HUMAN GEOGRAPHY
THE LAND

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By

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PREFACE

This book has been written for the students of graduate and post graduate classes of the Indian Universities. All aspects of the subject have been given due consideration interaction between man and his environment and has been discussed to a depth which is easily comprehensible and which as far as possible presents a correct perspective for undergraduate. The text has been effectively illustrated with an adequate number of maps and diagram. Statistics given in this book can be relied upon as they have been taken mostly from the publication of the control and state government.

Suggestions for improvement of this book are solicited. They will be gratefully received and acknowledge.

Author

CONTENTS

Preface
1. The Locational Setting 1
2. Climate 26
3. Atmosphere Structure 88
4. Soil 133
5. Relief and Geology 157
6. Natural Vegetation and Forest Resources 243
7. Droughts and Floods 282
8. Drainage 294

1

THE LOCATIONAL SETTING

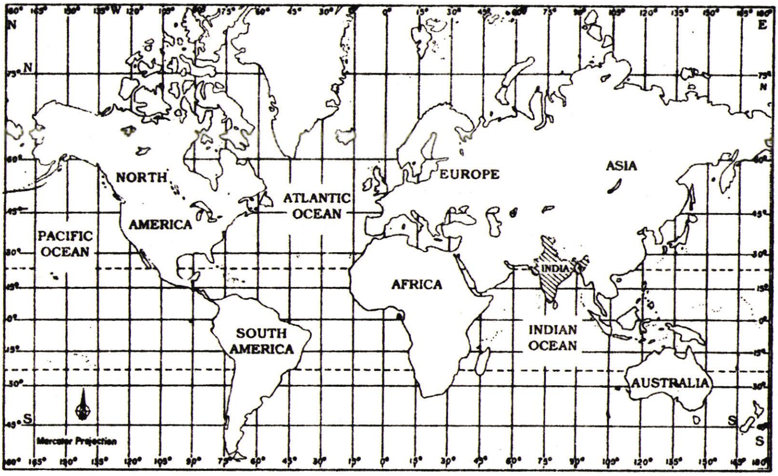
INTRODUCTION

India is one of the few ancient civilisations. Today, it is the largest democracy in the world. Its Journey through corridors of time has been long and eventful. Despite many ups and downs it has moved forward displaying remarkable vitality and continuity. Its geography has also contributed significantly in the making of its history.

Location and Size

India occupies title south-central peninsula of Asia (Fig. 1.1). It consists of the mainland and two groups of islands namely Lakshadweep in the Arabian Sea, and the Andaman and Nicobar Islands in the Bay of Bengal.

The mainland of India extends between 8°4'N and 37°6'N lattitudes, and 68°7'E and 97°25'E longitude. Find out the names of states in all the four major directions where these extreme points are located. Kanyakumari, the southern most tip on the mainland Is situated on three seas. Which are they? To the south-east and the south-west of the mainland, lie the Andaman and Nicobar Islands, and the Lakshadweep respectively. They appear as a long tail spread over a large area. The Andaman and Nicobar Islands are located far away from the Indian coastline. The southern-most point of the Indian Union is Indira point. It is located on this island group not very far from Indonesian islands (Fig 1.2). Lakshadweep Islands are comparatively less scattered and are also nearer to the Indian coast. India has a very long coastline, which is about 7500 km long.


N
E
NORTH
AMERICA
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ATLANTIC
OCEAN
EUROPE
ASIA
INDIA
AFRICA
SOUTH
AMERICA
INDIAN
OCEAN
AUSTRALIA
S
Mercator Projection

Fig. 1.1 : Location of India in the world map.

Look at Fig. 1.2 carefully. You will notice that the southern tip of the Indian Republic misses the equator by only a few degrees. Being situated totally north of the equator, India belongs to the northern hemisphere. If we divide the globe vertically into eastern and western hemispheres, in which hemisphere will India lie?

With an area of about 3.28 million square km, India is the seventh largest country in the world. Still it may not be considered too large because it has only 2.42 per cent of the world's total land area. Six other countries, larger than India in area are:

(i) Russia,

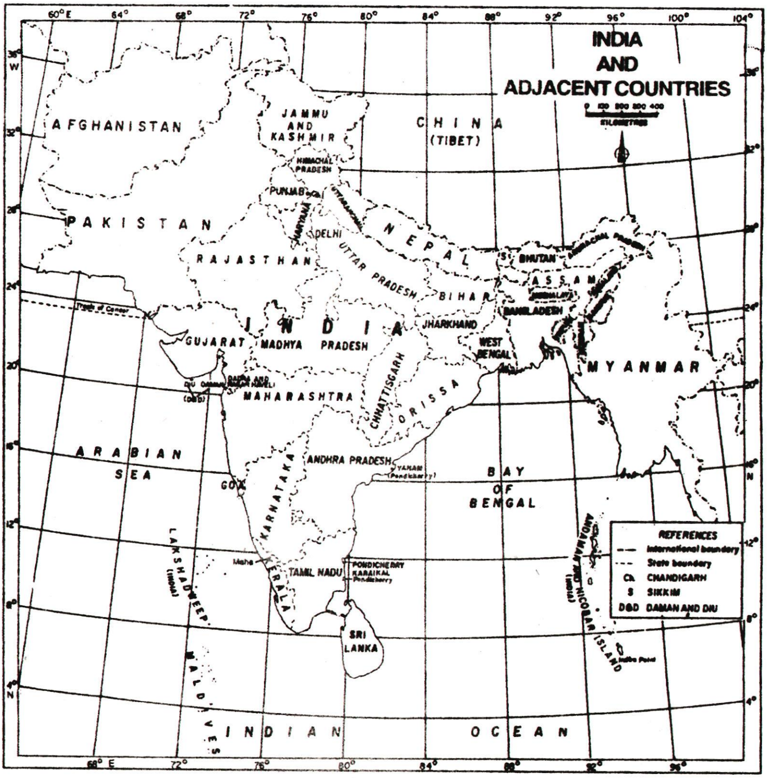
(ii) Canada,

(iii) China,

(iv) United States of America,

(v) Brazil, and

(vi) Australia.


INDIA
AND
ADJACENT COUNTRIES
0 100 200 300 400
KILOMETRES
60° E
64°
68°
72°
76°
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88°
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96°
100°
104°
36°
32°
28°
24°
20°
16°
12°
8°
4°
N
AFGHANISTAN
PAKISTAN
JAMMU AND KASHMIR
HIMACHAL PRADESH
PUNJAB
HARYANA
UTTARANCHAL
DELHI
RAJASTHAN
UTTAR PRADESH
CHINA (TIBET)
NEPAL
BHUTAN
ARUNACHAL PRADESH
ASSAM
MEGHALAYA
BANGLADESH
BIHAR
JHARKHAND
WEST BENGAL
Tropic of Cancer
INDIA
GUJARAT
MADHYA PRADESH
CHHATTISGARH
ORISSA
DIU
DAMAN AND NAGAR HAVELI
(D&D)
MAHARASHTRA
MYANMAR
ARABIAN SEA
GOA
ANDHRA PRADESH
YANAM (Pondicherry)
BAY OF BENGAL
KARNATAKA
LAKSHADWEEP (India)
Mahe
KERALA
TAMIL NADU
PONDICHERRY
KARAIKAL (Pondicherry)
SRI LANKA
ANDAMAN AND NICOBAR ISLAND (India)
Indira Point
MALDIVES
INDIAN OCEAN
REFERENCES
International boundary
State boundary
Ch. CHANDIGARH
S SIKKIM
D&D DAMAN AND DIU

The administration headquarters of Chandigarh, Haryana and Punjab are at Chandigarh. Responsibility for correctness of Internal details shown on the map rests with the publishers. "Based upon Survey of India map with the permission of Surveyor General of India". The Interstate boundaries between Arunachal Pradesh. Assam and Meghalaya shown on this map are as Interpreted from the North-Eastern Areas (Reorganisation) Act, 1971, but here yet to be verified. The territorial waters of India extended into the sea to a distance of twelve nautical miles measured from the appropriate base line.

Fig. 1.2 : India-political with immediate neighbours.

Each one of them is two to five times larger than our country.

It is Interesting to note that the latitudinal and longitudinal extent of the country is almost the same in degrees *i.e.*, about 30 degrees. But, in kilometres, the north-south distance (about 3,200 km) is more than that of the east-west distance (approx.

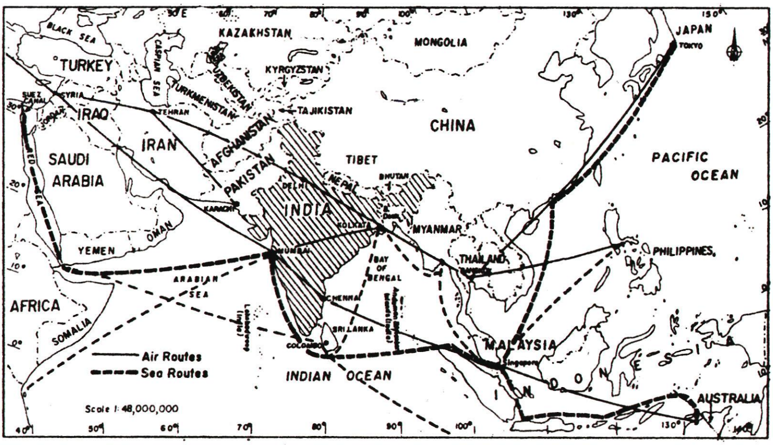
3000 km). Why is it so? Due to vast longitudinal extent, the time difference between the two extreme points in the east and the west is of two hours. In other words, when the sun rises in Arunachal Pradesh, it is still night in Gujarat. As such, time along the Standard Meridian of India (82°30'E) passing through Allahabad is taken as the standard time for the whole country. Find out why this meridian was selected?

The Tropic of Cancer (23°3'N) divides the country into almost two equal parts. The northern part is a broad region spreading east-west. It consists of the plains and the Himalayan mountains. The area to the south of the Tropic of Cancer, are triangular in shape. Having a base in the north the land tapers towards the south. It mostly coincides with the peninsular plateau, but also includes the eastern and the western coastal strips.

India and the World

The Indian landmass is a southward extension of the continent of Asia. On its north, a chain of lofty mountains run east-west uninterruptedly for thousands of kilometres. They are such formidable barriers that land communication with Tibet and China is possible only through a few passes, which are located on high altitudes. On the south, the Indian peninsula is surrounded by the seas and the ocean from three sides. Yet, people have been coming and going through land and sea routes. However, the partially enclosed character of the land, on the whole, has strengthened its uniqueness by assimilating new cultural elements coming from outside and yet fostering unity and homogeneity in the Indian society remarkably well.

As you know, India belongs of he eastern hemisphere, which contains the Oriental World. In ancient times, the sea played an Important role in determining the nature of interaction. The central location of India at the head of the Indian Ocean was of great advantage. Countries of East Africa, West Asia, South and South-East Asia, and East Asia could be reached through sea routes. Hence, India established close cultural and commercial contacts with these countries. India's eminent position in the Indian Ocean realm justifies naming an ocean after it.


BLACK SEA
TURKEY
CASPIAN SEA
KAZAKHSTAN
UZBEKISTAN
TURKMENISTAN
KYRGYZSTAN
TAJIKISTAN
MONGOLIA
CHINA
JAPAN
TOKYO
PACIFIC OCEAN
SUEZ CANAL
SYRIA
JORDAN
IRAQ
TEHRAN
IRAN
AFGHANISTAN
PAKISTAN
SAUDI ARABIA
RED SEA
TIBET
NEPAL
BHUTAN
DELHI
INDIA
KARACHI
KOLKATA
MYANMAR
OMAN
YEMEN
MUMBAI
BAY OF BENGAL
THAILAND
PHILIPPINES
ARABIAN SEA
AFRICA
SOMALIA
CHENNAI
SRI LANKA
COLOMBO
Lakshadweep (India)
Andaman and Nicobar Islands (India)
MALAYSIA
Singapore
INDIAN OCEAN
INDONESIA
AUSTRALIA
Air Routes
Sea Routes
Scale 1:48,000,000
40°
50°
60°
70°
80°
90°
100°
130°
140°
150°
30°
20°
10°
0°

"Based upon Survey of India map, with the permission of Surveyor General of India." The territorial waters of India extend Into the sea to a distance of twelve nautical miles measured from the appropriate base line. The boundary of Meghalaya shown on this map is as Interpreted from the North-Eastern areas (Reorganisation) Act, 1971, but has yet to be verified. Responsibility for correctness of Internal details shown on the map rests with the publisher.

Fig. 1.3 : India on the international highway of trade and commerce.

Since the opening of the Suez Canal in 1869, distance between India and Europe has been reduced by 7000 km. India enjoys a favourable situation on the International highway of trade and commerce even today (Fig. 1.3). Unlike land-locked-countries (surrounded by land on all sides) it has an easy access to outside world. The ocean routes from East and South-East Asia, and Australia to Africa, and Europe pass through the Indian Ocean. India is connected with Europe, North America and-South America through, both the routes the Cape of Good Hope and the Suez Canal. India can also reach Canada and the U.S.A. through the Strait of Malacca after crossing the Pacific Ocean.

India's Neighbours

India shares its land boundaries with Afghanistan and Pakistan in the north-west, China, Nepal and Bhutan in the north and Myanmar and Bangladesh in the east. The Island states of Sri Lanka and Maldives are our southern neighbours across the sea. Look at the relief map of Asia. You will notice that Pakistan, Nepal, Bhutan, Bangladesh and India form the most natural geographical unit, often referred to as the Indian sub-continent. It has a distinct physical and cultural Identity, which separates it from the rest of Asia.

INDIA'S GEOGRAPHICAL UNIT

The main land of India extends from 8°4' 28" north to 37° 17' 53" north latitudes and from 68°T 53" east to 97° 24' 47" east longitudes. Thus, its latitudinal and longitudinal extent is approximately the same which is nearly thirty degrees. The Andaman and Nicobar Islands extend further southwards and add to its latitudinal extent. The southernmost point, known as the Indira Point in the Great Nicobar Island is at 6° 45' north latitude. The north south extent of the mainland of India from Kashmir in the north to Kanyakumari in the south is 3,214 km. Its longitudinal extent from the Rann of Kachchh in the west to Arunachal Pradesh in the east is 2,933 km. Thus, the latitudinal and the longitudinal distances are about one tenth of the circumference of the globe.

India is the seventh largest country of the world after Russia (1,70,75,000 sq. km.), Canada (99,76,132 sq. km.), China (95,97,000 sq. km.), the U.S.A. (90,72,340 sq. km.), Brazil (85,11,965 sq. km.) and Australia (76,82,300 sq. km.). India 32,87,263 sq. km. India accounts for about two per cent of the total surface area of the world. India is nearly twenty times as large as Great Britain, the country which ruled us for about two centuries. Many of the Indian states are larger than several countries of the world.

The Tropic of Cancer passes through the middle of the country dividing it into two latitudinal halves being about 15° from either end. But the northern portion is very broad and the area to the north of tropic of cancer is nearly twice the area which lies south of it. The enormous width of India is often forgotten, being overshadowed by the more popular statistics of its length. We are habitual of expressing the dimension of the country as *'from Kashmir to Kanniyakumari' and not from 'Rann of Kachchh to Arunachal Pradesh'*. The east-west extent of India is almost equal to the combined longitudinal extent of Spain, France, Germany, Belgium, the Netherlands and Poland. South of 22° north latitude, the country tapers off into the Indian ocean as a peninsula and divides this ocean into two arms—the Arabian Sea in the west and the Bay of Bengal in the east.

Naturally, India, as being divided into northern temperate and southern tropical lands by the Tropic of Cancer. Thus, the temperate part of the country should be twice as much as its tropical part. But India has always been treated as a tropical country for two widely different reasons. The reasons are those of physical and cultural geography. The country is separated from the rest of Asia by a mountain wall forming an insulated compartment. Its climate is dominated by the tropical monsoons and the temperate air, masses are restricted by the mountain chain. Further, although the night temperatures in January at several places in Punjab may come down to the level of those prevailing in temperate lands, yet clear skies and intense insolation raise the day temperatures to a tropical level, so that the entire area south of the Himalayas is essentially tropical from climate point of view. Outside the Himalayas, almost everywhere the agriculture is tropical in type. As per cultural geography, the culture of India is totally different from that of the temperate countries of the western civilisation.

India along with its neighbouring countries, is a well defined geographical unit. South of the mountain chain, India, Pakistan, Bangladesh, Nepal and

Bhutan form a definite realm of South Asia which is often referred to as the Indian sub-continent. India alone accounts for about three-fourths of the total area of the sub-continent. According to Prof. Chisholm, there is no part of the world better demarcated by nature as a region by itself than the Indian *sub-continent*'. But some Indian Geographers are of the view that the use of the term sub-continent for India is a misnomer and is a legacy of the British rule which tended to divide the area on the basis of region and religion. These geographers contend that this expression has never been used for much vaster and more diverse geographical units like China and Russia. It is worth mentioning that the sub-continental theory of the

Britishers worked very well in dividing the area into different nations giving credibility to their basic policy of '*divide and rule*'. Total area of the country before partition was 42,27,378 sq. km. The partition of the country on 15th August, 1947 gave birth to a new country of Pakistan. This led to a loss, of 7,96,095 sq. km. area of West Pakistan (now called Pakistan) and 1,44,020 sq. km. of East Pakistan (the present Bangladesh). Thus, the present extent of the country is reduced to about three-fourths of its original size. Consequently, some scholars tend to replace the term Indian sub-continent by South Asia which includes, India, Pakistan, Bangladesh, Nepal, Bhutan, Sri Lanka and sometimes even Afghanistan.

This country has been variously named as *India, Hindustan, Bharat and Aryavarta.* The word India has its origin in the Greek literature meaning the land of 'Indoi', the people living near the *Indos* (latin Indus). Persians and Greeks extended the name *Sindhu*—'the river' from the Indus. Thus, it was called *Hindustan*—the land of Hindus in Persian and other West Asian languages. In the Hindu literature the sub- continent as a whole is styled as *Bharat* or *Bharat-Varsha*, the land of the legendary King Bharata who visualised the fundamental unity of the country. In the European languages it is popularly known as *India.* The name Aryavarta refers to the land of the Aryan race. At present only *India* and *Bharat* are officially recognised, although, *Hindustan* is also in common use.

INDIA'S FRONTIERS

Encompassed between the Himalayas and the Indian Ocean, India has both land and water frontiers.

Land Frontiers

India has 15,200 km. long land frontier to its north-west, north and north-east. This frontier is provided by the high Himalayan mountains which are world's most elevated ranges. Large parts of these mountain ranges are far above the permanent human habitation and remain snow covered for most part of the year. The Himalayan ranges form a natural frontier between India and China. In the north- west, India's Jammu and Kashmir share the international border with

Sinkiang and Tibet in China. Towards its east, Himachal Pradesh and the mountain region of Uttar Pradesh have common frontier with Tibet. Nepal has its border with Uttar Pradesh and Bihar. West Bengal and Sikkim also touch the Nepalese border for a small distance. To the east of Bhutan, the crest of the Himalayan range is known as *Mc Mahon Line.* This was demarcated by Henry Mv Mahon in 1914 and acts as the dividing line between India and China.

Till recent years, the Himalayan mountain ranges in the north formed a formidable barrier giving natural protection to India. But (he Chinese aggression in October, 1961 exploded this myth and the Himalayan mountain ranges can no longer be looked upon as an invincible barrier created by nature.

India's frontiers with Pakistan are artificial and unsatisfactory except in some limited and uninhibited dry parts of the Thar Desert. In Punjab, the frontier runs through a smooth and fertile plain, which is purely man made. The Indian frontier with Pakistan in Kashmir is still disputed and has led to strained relations between the two countries since partition in 1947. The nature of frontier between present India and Pakistan has given birth to many problems on the international scale, the most outstanding being the problems of infiltration, terrorism and smuggling.

The eastern boundaries of India are formed by a complex chain of the Himalayan offshoots consisting of the Mishmi, the Patkai, the Naga hills, the Barail range, the Mizo hills and finally the majestic Arakan Yoma mountain range. The Arakan Yoma is submerged in the Bay of Bengal for sufficiently long stretch and emerges again in the form of Andaman and Nicobar Islands.

Between the eastern states of Assam, Meghalaya, Tripura and Mizoram on one hand and West Bengal on the other hand, lies Bangladesh. The boundary line between India and Bangladesh criss-crosses the vast Ganga-Brahmaputra delta. This boundary runs through an entirely flat country, in which there is not even a small mound or hill which could be used for demarcating the boundary between the two countries. It is, therefore, a very unsatisfactory border because it fails to separate the people living on either side of the frontier. This has led to a serious problem of refugee influx, particularly from Bangladesh to India.

From the above discussion, it may be concluded that the land frontiers of India except the northern and eastern frontiers, formed by the Himalayas and their offshoots, are far from being geographic or natural; on the other hand, they are essentially man-made and unsatisfactory from the geopolitical viewpoint;

Water Frontiers

About 6,100 km. long coastline of mainland of India is washed on three sides of the country by the Indian Ocean and its two arms namely the Arabian Sea in the west and the Bay of Bengal in the east. If we add to this the, coastlines of Andaman and Nicobar Islands in the Bay of Bengal and Lakshadweep Islands in the Arabian Sea, the total coastline stretches to 7,517 km.

Next to the Himalayas, the Indian Ocean is the most dominant factor which has influenced' the destiny of India. It is through the waters of the Indian Ocean that India could establish her trade contacts with the neighbouring countries in the historic past. One of the greatest climatological phenomena, the Monsoon winds, have their origin in the Indian Ocean. Our water frontiers had been treated to be safe in the past. But the recent technological advancements in naval warfare have made these frontiers vulnerable to attack by the enemy forces and this has necessitated greater defence preparedness.

ROUTES INTO INDIA

It has already been mentioned that India is separated from the rest of Asia by a broad *no-man's land* of mountains, from the north, north-west and north-east. Most of the Himalayan ranges are either ice bound or covered by thick vegetation and offer an almost an impenetrable wall. This makes India an intelligible isolate. However, there are a few passes which provide routes into India.

Three high passes viz. *Muztagh* (Snowy mountain), the *Karakoram* and the *Changchemo* are all over 6,000 metres above sea level and offer little scope for interaction between the two sides of the mountain ranges. Some passes in the high Himalayas such as *Burzil* and *Zojilla* in Jammu and Kashmir; *Bara Lacha La and Shipki La* in Himachal Pradesh; *Tahgia La, K-Lang, Niti* and *Lipu Lekh* in Uttar Pradesh; *Nathu La* and *Jelep La* in Sikkim are used for crossing the main Himalayan range.

Towards the north-west, the frontier formed by the Himalayas is continued by the Karakoram range and the *Hindukush*. Further south lie the *Safed Koh, Sulaiman* range and the *Kirthar range*, which separate India from Afghanistan and Baluchistan. Thus, the real natural frontier of India lies far away from the present man-made and artificial frontier between India and Pakistan which is the creation of partition of the country in 1947. The mountain ranges here become shallow and narrow down to less than 500 km. between Turkestan and the Punjab (undivided) Plains. The Hindukush is pierced by numerous passes which are snow covered in winter but can easily be crossed in other seasons. There are a few passes which are less than 1600 metres above sea level and offer easy access into India.

The passes of *Khyber, Malakand, Tochi, Gomal* and *Kohat* have their base in Badakhshan province of Afghanistan and provide passage from Afghanistan to the Indian subcontinent. Towards the south, the highways of Herat and Seistan converge at Quetta. It is worth noting that Quetta lies at the head of the *Bolan pass* and provides one of the most significant gateways into the Indian sub-continent.

History reveals that the barrier was at no time an insuperable one, and at all periods, invaders, settlers and traders have found their way over the high and desolate passes into India, while Indians have carried their commerce and culture beyond her frontiers by the same routes. India's isolation has never been complete, and the effect of the mountain wall in developing her unique civilisation has been over emphasised. People after people, literally nations have pressed into the

Indian sub-continent through these passes and changed the fate of various dynasties in India. Hordes of invaders have attacked and conquered India through these passes.

Perhaps the earliest immigrants of civilised man into India were the *Dravidians* about whom little evidence is available. It is believed that they migrated into India from the *Tigris Valley* along the *Makran Coast* of the present Pakistan. This was followed by many others in the pre-historic times, the most prominent being the *Aryans* who migrated by the Kabul approaches. Later in the historic times, several other people such as *Greeks, Parsees, Huns, Mughals and Mohammadans* entered India mostly through these passes.

In the east, the hills forming the boundary between India and Myanmar are comparatively low and rarely exceed 3,000 metres in elevation. But the dense forests, heavy rainfall for half the year, difficult terrain and a large number of swift flowing rivers have acted as effective barriers between the two countries. The only passages are along the courses of rivers Brahmaputra, Mekong, Salween and Irrawaddy—the main gaps being the *Ann, Teju, Manipur, Tulu, Tongap*, etc. Therefore, not many foreigners have crossed through this frontier into India. In fact, reaching Irrawaddy valley in Myanmar from India is much easier by sea than by land. The opening of new trade route in 1995 connecting *More* in Manipur with *Tamu* and *Myanmar* may help in developing trade and cultural relations between the two countries.

It is surprising that until the coming of European seamen, no considerable power was founded in India from the sea; but some were from India. Initiative to the east really came from India. Hindu traders and colonisers took their civilisation by sea to the south-east Asian countries. Buddhism originated in India and spread to the whole of eastern Asia. The Cholas had an empire in the East Indies. Several other Hindu cultural traits are still found in large parts of the Far East.

LAND OF DIVERSITIES

India is a land of great diversities and contrasts. It is but natural that a vast area as the Indian sub- continent should have considerable physical diversity. *The extremes of physical and human geography of India are extreme indeed.* In the south is the Plateau which is one of the oldest and least disturbed land mass on the earth's surface. Its rocks have never been extensively covered by sea since their formation in the pre-cambrian period over 3,000 million years ago. In contrast to this, the Himalayan mountain ranges and the Great Plains represent the most recent formations. The denudational processes have made these contrasts still sharper. While the mountain ranges in the north have very youthful topography with sharp peaks and steep-sided valleys, the Peninsular plateau shows old and senile topography with gently rising ridges and wide valleys. The Aravalis and the Himalayas are perhaps the oldest and the youngest ranges on the earth's surface. The differences are most striking even in the landforms of recent origin. Within a distance of a few hundred kilometres from north to south, one can reach from the highest peak of the world to the flat, featureless and monotonous plain.

Even the rivers of the Himalayan and the Peninsular regions have contrasting characteristics. The Himalayan rivers have their origin in the snow covered areas. As such, they receive water even in dry season due to snow melt and are perennial. On the other hand, rivers of the Peninsular plateau carry only rain water and the quantity of water carried by them decreases considerably in dry season. They are, therefore, termed as seasonal rivers. Moreover, the rivers of the Peninsular plateau have reached maturity whereas the Himalayan rivers are still in their youthful stage. Most of the Himalayan region is made of sedimentary rocks while The Peninsular plateau, has mostly igneous and metamorphic rocks. Hemmed between the Himalayas in the north and the Peninsular plateau in the south, lies one of the greatest alluvial plains of the world. This great plain stretching in a great curve from Arabian Sea to the Bay of Bengal, consists of extremely fertile soils washed down by the streams and rivers for thousands of years.

Climatic contrasts are no less pronounced than the physiographic contrasts. Although, a typical monsoonal realm, Indian climate exhibits a wide range of climatic variations. While the mercury may dip to (–) 40°C during winter nights at Dras or Kargil in Jammu and Kashmir, the temperature may stand at a fairly high level of 20°C to 25°C at Chennai. In summer, the day temperature at Banner in Rajasthan may soar to 48°C-50°C while the higher reaches of the Himalayas may still remain snow covered. The differences are equally striking in rainfall patterns also. Mawsynram near Cherrapunji receives an annual rainfall of over 1,100 cm. as compared to only 12 cm. received at Jaisalmer. Several places in Garo hills receive more rainfall in a single day than received by Jaisalmer in a long span of ten years. The people of Mumbai experiencing maritime climate may not have any idea of extremes of climate. But Delhi its living in continental climate have to pass through the entire cycle of seasonal changes. As a result of climatic extremes, the natural vegetation varies from dense tropical evergreen forests of the Western Ghats, North-Eastern states and Andaman and Nicobar islands to the scanty scrub bush vegetation of the Thar Desert and its adjoining areas.

Extremes and diversities of the physical features and climatic conditions have produced human heterogeneity of a high order. On one end of the scale are the vast uninhabited areas of Ladakh and the Thar desert and on the other end are the river valleys and deltas accounting for some of the highest population densities in the world and that too based on purely agrarian economy. The length and breadth of the country comprises a rich mosaic of religions, languages, cultures and races and is, thus, heterogeneous in character and spirit. All levels of economic development from that of the *stone age* to the *satellite* and *computer* age are seen in the country. In large parts of the country, purely tribal, agricultural, industrial and commercial economies exist simultaneously.

Considering its physical and cultural diversities India is often called the '*epitome of the world*'.

UNITY IN DIVERSITY

It must not be forgotten that the above mentioned diversity of India is based on its underlying unity. India has been able to project itself as a single territorial unit in the face of physical, political, social and economic contrasts. The unifying role of the Great Plains between the Himalayan ranges on one hand and the Peninsular India on the other can hardly be ignored. Climatically, the monsoonal rhythm of seasons provides a strong element of uniformity. The concentration of monsoonal rainfall to a few months in a year and the associated agricultural activities are an all India phenomena. Many of our cultural traditions are strongly tied to the monsoons. Our saints have spread the message of universal brotherhood which has helped a great deal in uniting different sections of society in India and making the country a united nation.

The *Ramayana* and *Mahabharata* have provided themes even for tribal dances and music for thousands of year and still continue to do so. Although, *Hinduism* is the way of life for majority of Indians. *Hinduism* and Islam are intertwined into a composite mapix on the Indian land. It is in this composite matrix that integration of India is strongly rooted. In fact there are more Muslims in India than in Pakistan. Centuries of foreign rule failed to disrupt our cultural ties.

On economic front, the development of inter-regional linkage and the emergence of a national home market have played a significant role in uniting the country. For example, tea from Assam, wheat from Punjab and Haryana, minerals from Chotanagpur plateau and spices from the hill areas of the southern states are used all over the country and in turn these areas obtain items required by them from other areas. This process has been accelerated by the development of transportation and communication.

LAND OF POTENTIALITIES

India is blessed with a large variety of natural resources in huge quantities. Many of them still await exploitation. Whereas nature has been bountiful to India, the inhabitants of this country have not been able to develop requisite technology, in the modern context, to harness these resources. India is, therefore, often referred to as *'poorly developed rich country'* or *'a rich country inhabited by poor people'*. Sometimes it is also called the *'land of the future'* or *'land of potentialities'*.

India's huge mineral wealth encompasses a wide range which is supposed to be sufficient enough for developing a modern industrial base. India is particularly rich in the deposits of high grade iron ore, manganese and chromite. Her reserves are said to be adequate with respect to limestone, bauxite, coal and strategic minerals.

Although, India's forests resources are not very large and there is urgent need to increase the area under forests to meet the growing demand for forest products and to maintain the ecological balance, yet they are able to feed many forest based industries like paper, plywood, match box, furniture, resins, lac, etc.

India has vast resources of both surface and ground water which can be used for irrigation, power generation, industries and for drinking purposes. Only a small proportion of this natural resource has actually been utilised offering us enormous potentialities.

It is estimated that about one fourth of the total cropped area is presently irrigated whereas about half of the total cropped area can be irrigated by making optimum use of the water resources available to us. Similarly only one-fourth of the total water power potential in the country is actually used. Indian rivers offer numerous sites suitable for generating hydroelectricity.

India is one of the leading agricultural countries of the world and agriculture is the most important occupation of Indians. But the overall production and the yields per hectare are very low as compared to the advanced countries. The total production can be increased only by increasing the yield as all the cultivable land has already been brought under plough. This requires intensive use of high yielding varieties of seeds, fertilisers and irrigation facilities.

Of course, the greatest asset of India is its population which is second only to that of China. The poverty stricken, much cursed and ever growing vast ocean of humanity, if properly channelized, could be converted into huge manpower resource and could prove boon, rather than bane, for national development. The only problem is that not many avenues are open due to backward state of economy in the present day context.

INDIA'S NEIGHBOURING COUNTRIES

As mentioned earlier, Indian borders are both natural and man made. In the north, north-west and north-east, India's international boundaries are formed by the lofty Himalayas and its offshoots. In the south, south-west and south-east, its coast is washed by the Indian Ocean, Arabian Sea and Bay of Bengal respectively.

Immediately across the Indian border in the north is the Tibet Plateau, the land of the sacred Kailash and the Mansarover Lake. Tibet has deep economic and cultural relations with our country since ancient times. *Lhasa*, the spiritual head quarter of the *Tibet* is only 300 km. away from the Indian order. But now it has been annexed by China and is considered to be a part of that country. Therefore, our immediate neighbour touching major part of our northern boundary is China. Our next immediate neighbour in the north is the Himalayan kingdom of Nepal. We have very strong historical and geographical links with Nepal. East of Nepal, across Sikkim, is Bhutan. At the easternmost point of the Indian border is the north-eastern *tri-junction* where India, China and Myanmar meet. To the east of the eastern offshoots of the Himalayas, lies Myanmar.

To the west, our immediate neighbour is Pakistan—a creation of partition of the country in 1947. It is interesting to note that the apex of the north Indian triangle is the meeting place of five countries of Asia viz. India, China, Tajikistan, Afghanistan and Pakistan. Therefore, it assumes a great strategic significance.

Across the sea, our immediate neighbour is Sri Lanka. It is separated from the mainland of India by the narrow Palk Strait. *Maldive* Islands is another neighbour situated in the south of the Lakshadweep Islands. Sumatra Island of Indonesia is nearer to Nicobar Islands than any part on the mainland of India, and so are parts of Thailand and Malaysia.

INDIA AND THE ORIENTAL WORLD

The Oriental world includes into its fold the countries of East Africa, South West Asia, South Asia and the South East

Asia. These countries surround the Indian Ocean which unites them through sea routes. Economically and culturally, India's major contacts with outside world for the last two millennia have been by sea, earning India, the title of '*Mistress of the Eastern Seas*'. The opening of the Suez Canal has brought the countries of Southern Europe and North Africa very close to India. In ancient days, the boats of the Babylonians, the Egyptians and the Phoenicians used to sail in the Arabian Sea. Hindu and Buddhist cultures and religions spread to far off areas towards south and east Asia. There are a number of temples in Thailand with *slokas* from *Ramayana* engraved on the walls. Bali in Indonesia was the seat of Hindu Kingdom. Mauritius in the Indian Ocean is a '*miniature India*'.

Our relationship through land frontiers are much older than our maritime contacts. Passes, gorges and valleys in the mountain chains offered passages to travellers in the ancient times. Waves of settlers from the north-west were lured by the riches of India in general and that of the Great Plains in particular. Mongols, Turks, Arabs and Iranians entered India as conquerors and settled down here. These settlers got assimilated in the national main stream with the passage of time which led to a mixture of races, cultures, people and ethnic groups. Some of the invaders brought architectural excellence to India and took back to their homeland the Indian numerals, the decimal system and the ideas of Upnishads. Buddhism travelled from India to Tibet through land routes and further crossed over to China, Korea and even Japan. Thus, India is an integral part of the oriental world and holds a significant position in the region;

STRATEGIC SIGNIFICANCE OF INDIA

India stands at the head of the Indian Ocean at the very centre of the *Eastern Hemisphere* commanding trade routes running in all directions. Its location, size and economic resources have made it the most dominating country among the *littoral states*. Indian Ocean is the only ocean in the world which has been named after a country *i.e.,* India. This only proves the great prominence enjoyed by India in early days when these oceans were given their names. The Indian Ocean has never been a barrier between the countries. On the contrary it has served as a great linkage between the countries lying on its coasts and even further beyond.

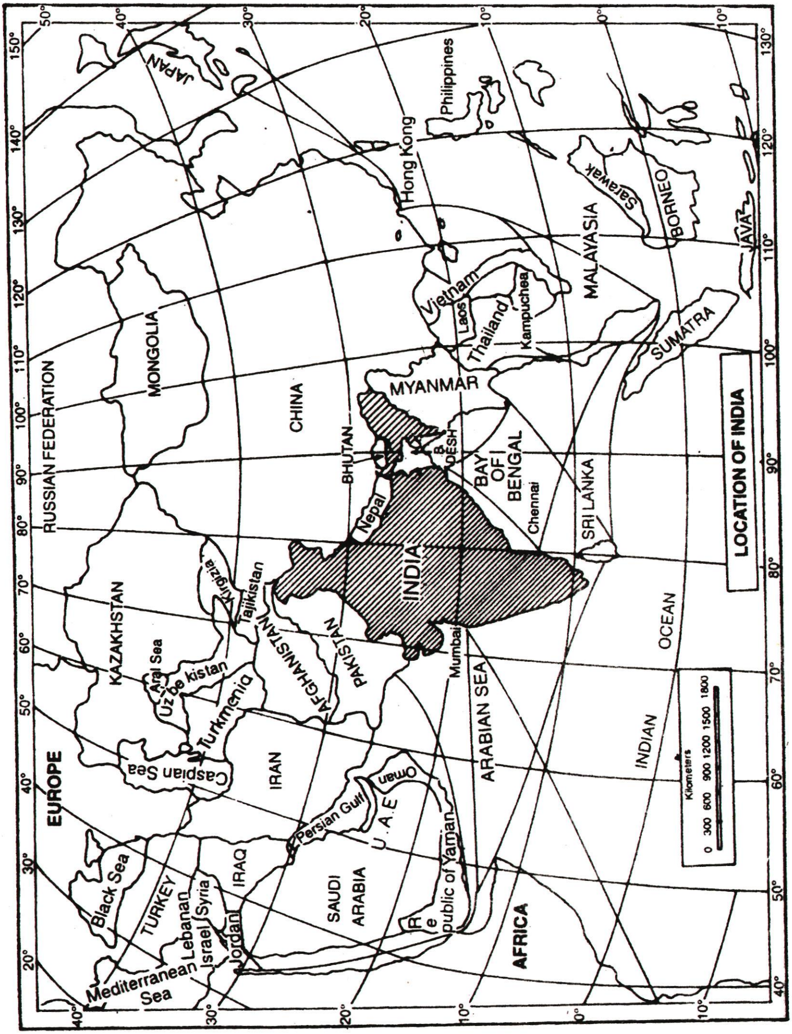

LOCATION OF INDIA
RUSSIAN FEDERATION
EUROPE
KAZAKHSTAN
MONGOLIA
CHINA
JAPAN
Philippines
Hong Kong
Vietnam
Laos
Thailand
Kampuchea
MALAYASIA
Sarawak
BORNEO
JAVA
SUMATRA
MYANMAR
B DESH
BHUTAN
Nepal
INDIA
BAY OF BENGAL
Chennai
SRI LANKA
Mumbai
ARABIAN SEA
INDIAN OCEAN
PAKISTAN
AFGHANISTAN
Tajikistan
Kirgizia
Uzbekistan
Turkmenia
Aral Sea
Caspian Sea
IRAN
IRAQ
Persian Gulf
U.A.E
Oman
Republic of Yaman
SAUDI ARABIA
AFRICA
Jordan
Israel
Lebanan
Syria
TURKEY
Black Sea
Mediterranean Sea
Kilometers
0 300 600 900 1200 1500 1800
150° 140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40° 30° 20°
130° 120° 110° 100° 90° 80° 70° 60° 50° 40°
50° 40° 30° 20° 10° 0° 10°
40° 30° 20° 10° 0° 10°

Fig. 1.4 : Location of India at the head of the Indian Ocean in the Oriental World and on the International Highway of Trade and Commerce.

The trans-Indian Ocean routes connecting the developed countries of Europe in the west and the developing countries of Asia in the east must skirt the shores of India. We can reach West Asia, Africa and Europe from the west coast and South East Asia, Far East and Oceania from the eastern coast. The Indian Ocean, thus, bridges a gap between east and west. No other country has such a long coastline on this ocean as India has. Therefore, the *Indian Ocean is truly Indian Ocean*. Most of the air routes between Europe, West Asia and Africa in the west and East Asia, South East Asia, Japan and Australia in the east also pass through India.

The centrality and the consequent significance of India to broader Indian Ocean geopolitics and economics has been proved beyond doubt. It was India's status as the principal entrepot in a highly profitable oceanic trade structure which attracted the West Asian Muslims, and the European colonial powers towards India. India became the *'jewel in the crown'* of the vast British empire due to its wealth and because of its role as a fulcrum upon which the imperial and commercial system in Asia was balanced.

India thus, commands an important strategic position on the globe with respect to trade as well as social and cultural interaction. India is a concept. India is an experiment through ages. India is unique, India is India—no parallel example exists.

INDIA'S POLITICAL DIVISIONS

About two centuries of British rule left India fragmented into 562 small princely states at the time of independence in 1947. The constitution of India was adopted with the establishment of Democratic Republic of India on 26th Jan., 1950 and India was recognised as a Union of States. In order to respect the sentiments of the people living in different parts of the country and to undo the fragmented legacy of the British misrule, the State Reorganisation Commission was set up in 1953. This commission suggested the division of India into 14 states and 6 Union territories. This suggestion was accepted with some modifications and the country was divided on linguistic basis according to the States Reorganisation Act of 1956. The former French territories (Pondicherry, Karaikal and Yanam on the east coast and Mahe on the west coast) on the mainland of India, ceded to India in 1956.

The first linguist reorganisation of states in India occurred in the aftermath of the movement in the Andhra region of the old Madras province. Telugu speaking areas were separated from the composite Madras State and a new Andhra State came into being on October 1, 1953. Telangana area was added to Andhra State and Andhra Pradesh was formed on November 1, 1956. On 1st May, 1961, the erstwhile bilingual province of Bombay was bifurcated into Gujarati speaking Gujarat and Marathi speaking Maharashtra. The Portuguese colonies of Goa, Daman and Dim were the last remnants of the European occupation in India. These were liberated from the foreign yoke and they became part of India on 16th Dec., 1961. This completed the territorial integration of the Indian Union.

Several new states have been carved out in the north-eastern region of the country in response to demands by the tribals. In 1957 the north eastern part of Assam was separated and was designated as North-East Frontier Agency (N.E.F.A.). The Naga hills territory was a centrally administered area and was known as the Naga Hills Tuensang Area. It was renamed as Nagaland in 1961 and was given the status of a state on 1st December, 1963.

Manipur became a Union Territory under States Reorganisation Act 1956 and was made full fledged state of Union in 1972. Meghalaya was created as an autonomous state within the state of Assam on 2nd April, 1970. The full-fledged state of Meghalaya came into existence in January 21, 1972. Tripura was annexed to the Indian Union in 1947 and became centrally administered territory in 1956. It was granted statehood in 1972.

Thus, three states in the north-eastern region came into existence in 1972. Sikkim ceased as a protectorate of India in 1974 and became an Associated State of India thereafter. It became an integral part of India as a result of referendum held on April 14, 1975. The North-East Frontier Agency (N.E.F.A.) was given the new name of Arunachal Pradesh and was granted still statehood of February 20, 1987. Mizoram was one of the districts of Assam till 1972 when it became a union territory with the implementation of the North-Eastern Reorganisation Act. It was granted full statehood on February 20, 1987.

Turning again to the south, it is worth mentioning that the Mysore State, created in 1956, was renamed as Karnataka in 1973 on the demand of Kannada speaking majority of the area. Goa which was liberated in 1961 was conferred statehood on May 30, 1987 although Daman and Diu still remains as union territory.

In the north-western part of the country, the bilingual state of Punjab was divided into Punjabi speaking Punjab and Hindi speaking Haryana on 1st November, 1966. Thus the, new state of Haryana was born on this date tertain hill areas of erstwhile Punjab were transferred to Himachal Pradesh. It was granted full statehood on January 25, 1971.

There are some small scattered areas in the Union of India which are centrally administered and are known as Union Territories. As the things stand today the Indian Union comprises 28 states and 9 union territories (See Fig. 1.4 and 1.5), Their details are given in Table 1.1.

Table 1.1 : Political Divisions of India

Sl. No.	*State/Union Territory*	*Area in sq. km.*	*Capital*	*Rank in area among states*
1.	Andhra Pradesh	275,045	Hyderabad	5
2.	Arunachal Pradesh	83,743	Itanagar	13
3.	Assam	78,438	Dispur	14
4.	Bihar	99023	Patna	9
5.	Chhattisgarh	117,297	Raipur	
6.	Goa	3,702	Panaji	25
7.	Gujarat	196,024	Gandhinagar	7
8.	Haryana	44,212	Chandigarh	17
9.	Himachal Pradesh	55,673	Shimla	15
10.	Jharkhand	74,854	Ranchi	
11.	J&K	222,236*	Srinagar	6

12.	Karnataka	191,791	Bangalore	8
13.	Kerala	38,863	Thiruvananthapuram	18
14.	Madhya Pradesh	326,149	Bhopal	1
15.	Maharashtra	307,713	Mumbai	3
16.	Manipur	22,327	Imphal	20
17.	Meghalaya	22,429	Shillong	19
18.	Mizoram	21,081	Aizawl	21
19.	Nagaland	16,579	Kohima	22
20.	Orissa	155,707	Bhubaneshwar	10
21.	Punjab	50,362	Chandigarh	16
22.	Rajasthan	342,239	Jaipur	2
23.	Sikkim	7,096	Gangtok	24
24.	Tamil Nadu	130,058	Chennai	11
25.	Tripura	10,486	Agartala	23
26.	Uttar Pradesh	238,566	Lucknow	4
27.	Uttaranchal	55,845	Dehradun	
28.	West Bengal	88,752	Calcutta	12

	Union Territories	*Area in sq. km.*	*Capital*	*Rank in area among U.Ts.*
1.	Andaman & Nicobar Islands	8,249	Port Blair	1
2.	Chandigarh	114	Chandigarh	3
3.	Dadra and Nagar Haveli	491	Silvassa	4
4.	Daman & Diu	112	Daman	6
5.	Delhi	1,483	Delhi	2
6.	Lakshadweep	32	Kavaratti	7
7.	Pondicherry	492	Pondicherry	5
	India	**3,287,263**	**New Delhi**	

*Includes 78,114 sq. km. under illegal occupation of Pakistan, 5,180 sq. km. illegally handed over by Pakistan to China and 37,555 sq. km. under illegal occupation of China.

Source : Statistical Abstract of India, (1992) p. 2.

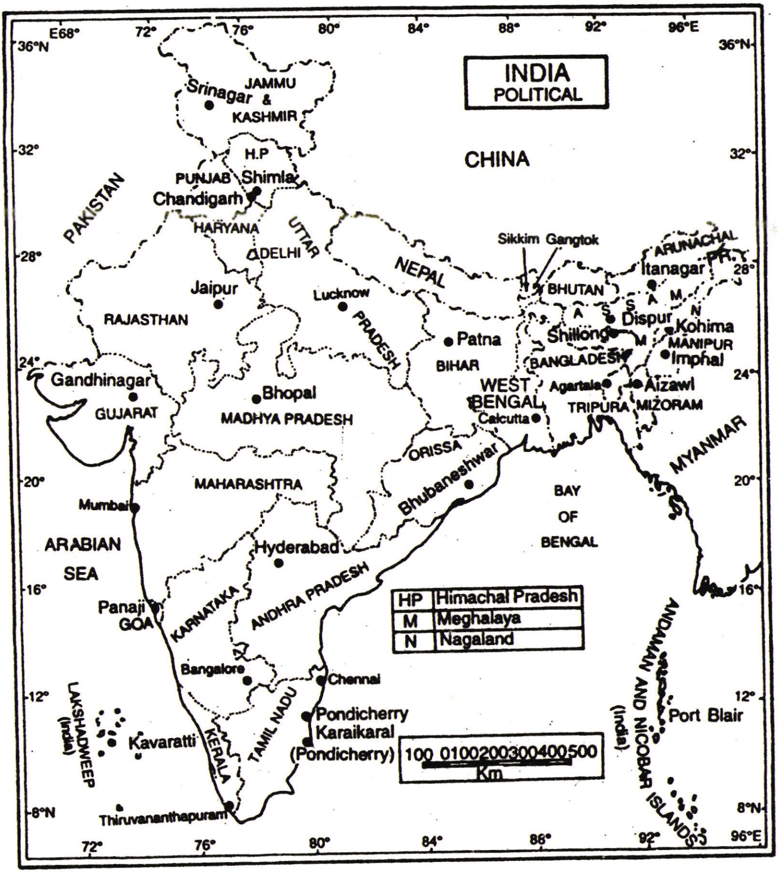

INDIA
POLITICAL
CHINA
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
MYANMAR
JAMMU & KASHMIR
Srinagar
H.P
Shimla
PUNJAB
Chandigarh
HARYANA
DELHI
UTTAR PRADESH
Lucknow
RAJASTHAN
Jaipur
GUJARAT
Gandhinagar
MADHYA PRADESH
Bhopal
MAHARASHTRA
Mumbai
BIHAR
Patna
WEST BENGAL
Calcutta
ORISSA
Bhubaneshwar
ANDHRA PRADESH
Hyderabad
KARNATAKA
Bangalore
GOA
Panaji
KERALA
Thiruvananthapuram
TAMIL NADU
Chennai
Pondicherry
Karaikaral
(Pondicherry)
LAKSHADWEEP (India)
Kavaratti
ANDAMAN AND NICOBAR ISLANDS (India)
Port Blair
Sikkim Gangtok
ARUNACHAL PR.
Itanagar
ASSAM
Dispur
Shillong
M
N
Kohima
MANIPUR
Imphal
Agartala
TRIPURA
Aizawl
MIZORAM
ARABIAN SEA
BAY OF BENGAL
HP Himachal Pradesh
M Meghalaya
N Nagaland
100 0 100 200 300 400 500
Km
E68°
72°
76°
80°
84°
88°
92°
96°E
36°N
32°
28°
24°
20°
16°
12°
8°N

Fig. 1.5 : Political Map of India.

It will be seen from Table 1.1 that three states of India have an area exceeding three lakh sq.km. each. The largest is Madhya Pradesh which accounts for 13.5 per cent of the country's total geographical area. This is followed by Rajasthan (10.4 per cent) and Maharashtra (9.4 per cent). Goa is so far the smallest state with only 0.11 per cent of the area of the Indian Union.

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2

CLIMATE

INTRODUCTION

Climate refers to the sum total of weather conditions and variations over a large area for a long period of time (more than thirty years). The elements of weather and climate are the same *i.e.,* temperature, atmospheric pressure, wind, humidity and precipitation You must have observed that the weather conditions fluctuate very often even within a day. But there is some common pattern over a few weeks or months, *i.e.,* days are cool or hot, windy or calm, cloudy or bright, and wet or dry. On the basis of the generalised monthly atmospheric conditions, the year is divided into seasons such as winter, summer or rainy seasons. The world is divided into a number of climatic regions. Do you know what type of climate India has and why is it so?

The climate of India is described as of *monsoon type*. Derived from an Arabic word '*mausim*', monsoon refers to the seasonal reversal in the wind direction through the year. This type of climate is found mainly in the south and the south-east Asia. Despite an overall unity and commonality in the general pattern, there are perceptible regional variations in climatic conditions within the country. Let us take two Important elements— temperature and precipitation, and examine how do they vary from place to place and season to season.

In summer, the mercury occasionally touches 50°C or more in some parts of the Rajasthan desert, whereas it may be around 20°C in Pahalgam and Jammu and Kashmir. On a winter night, temperature at Dras in Jammu and Kashmir may be as low as –45°C. Thiruvananthapuram, on the other hand, may have a temperature of +20°C.

Even from such crude facts we may infer that there are great variations In temperature in India from place to place or region to region and at least in several cases from season to season as well. In fact. In certain places there is wide difference between day and night temperatures. In the Thar Desert, the day temperature may rise to 50°C, and drop down to near freezing point the same night. On the other hand there is hardly any difference in day and night temperatures (7°C-8°C) in the Andaman and Nicobar Islands or in Kerala.

Let us now move to rainfall or precipitation. There are variations not only In the form and type of precipitation but also in its amount and the seasonal distribution. While precipitation is mostly in the form of snowfall in the Himalayas, it only rains over the rest of the country. The annual precipitation varies from over 400 cm in Meghalaya to less than 10 cm in Ladakh and Western Rajasthan. Most parts of the country receive rainfall in June- September. But some parts like Tamil-Nadu coast gets most of its rains during autumn and early winter-While the Western Disturbances bring rainfall to the northern part of the country during winter, in Tamil Nadu it is the northeast monsoons that cause rains.

In general, coastal areas experience less contrast in temperature conditions. Seasonal contrasts are more in the Interior of the country. There is decrease in rainfall generally from east to west in the Northern Plains. These variations have given rise to a variety in the lives of people-food, clothing and housing. But the overall unity of monsoon can also be seen through the main economic activity—agriculture and finer sensibilities like literature, music, dance and painting and celebrations of festivals.

World climates have been generally classified into certain types and subtypes on two bases *e.g.,* (i) empirical basis and (ii) genetic basis. The empirical classification of world climates is based on statistical data of climatic elements derived through observations and experiments while genetic classification is based on the causes or genesis of climatic phenomena and climatic variations. Though several scientists have attempted to classify world climates into certain types but the schemes of Wladimir Koeppen, C.W. Thornthwaite, and G.T. Trewartha are more commonly used.

CLASSIFICATION BY THORNTHWAITE

C.W. Thornthwaite, an American climatologist, presented his first scheme of classification of climates of North America in 1931 when he published the climatic map of North America. Later he extended his scheme of climatic classification for world climates and presented his full scheme in 1933. He further modified his scheme and presented the revised second scheme of classification of world climates in 1948. His scheme is complex and empirical in nature.

Precipitation Effectiveness

Precipitation effectiveness or precipitation efficiency refers to only that amount of total precipitation which is available for the growth of vegetation. He used precipitation efficiency ratio for the calculation of this amount of water available to vegetation. Precipitation efficiency ratio (P/E ratio) is calculated by dividing total monthly precipitation by monthly evaporation and precipitation efficiency index (P/E index) is derived by summing the precipitation efficiency ratios for 12 months of a year. (2) 1948 Classification.

The climate of a place, thus, is determined by combining the aforesaid elements of the climatic classification *e.g.*,, moisture index, thermal efficiency index, summer concentration of thermal efficiency, and seasonal moisture adequacy (aridity and humidity indices). Thus, the climate of a place is represented by four letters. For example– A A' a'r climate = Perhumid (A) megathermal (A') climate with summer concentration of annual thermal efficiency (PE in cm) of less than 48 per cent (a') and little or no water deficit (r) etc. On the basis of above indices the classification system becomes so complex due to large number of climatic types that it becomes difficult to represent them cartographically.

1931 Classification

Like Koeppen Thornthwaite also considered natural vegetation of a region as the indicator of climate of that region. He accepted the concept that the amount of precipitation and temperature had paramount control on vegetation but he also pleaded for inclusion of evaporation as important factor of vegetation and climate. This is why Thornthwaite used two factors, *e.g.*, precipitation effectiveness and temperature effectiveness, for the delimitation of boundaries of different climatic regions.

Evaluation of Thornthwaite's Schemes

In many aspects the 1931 classification scheme of Thornthwaite was almost similar to Koeppen's scheme because both had a few common points *e.g.*,

(i) Like Koeppen's scheme his scheme is also empirical as well as quantitative as the boundaries of different climates are determined on the basis of quantitative parameters derived from precipitation and temperature,

(ii) Vegetation is made as the basis for the identification of climatic zones,

(iii) Various letter combinations are used to designate different climatic types etc. The Thornthwaite's scheme differs from the Koeppen's scheme in that the former used two indices of precipitation efficiency and thermal efficiency for differentiation of different climatic types but the delimitation of climatic boundaries on the basis of these two indices becomes difficult and vague. Moreover, the Thornthwaite's scheme yielded the number of major climatic types (32) three times greater than Koeppen's climatic types. Like Koeppen's scheme Thornthwaite's scheme also became popular among zoologists, botanists and geographers but it was not appreciated by meteorologists and climatologists because this scheme did not include the causative factors of climates into the classification of world climates in different types. This scheme also suffers from a serious problem of non-availability of the data of evaporation for all the places. Thus, the lack of adequate climate data makes it difficult for the precise demarcation of climatic boundaries.

Though, 1948 scheme of climatic classification of Thornthwaite was thoroughly revised and modified and was based on 4 important indices of moisture index, thermal efficiency or potential evapotranspiration index, seasonal moisture adequacy (aridity and humidity indices), and summer concentration of thermal efficiency but no world map of different climatic types could be prepared. It may be pointed out that it becomes very difficult to cartographically represent a large number of climatic types identified quantitatively on the basis of aforesaid indices. Moreover, the data of potential evapotranspiration are not available for all the places for a worldwide classification of climates. The complex empirical formulae divided by Thornthwaite require regular data but these are not always forthcoming. They also involve a lot of calculations for determining the climatic type of a particular place. This is why his scheme could not get more popularity and recognition.

CLASSIFICATION OF G.T. TREWARTHA

G.T. Trewartha, an American climatologist, made several revisions and modifications in the scheme of climatic classification of Koeppen since 1930s and ultimately presented his simple scheme of climatic classification having a blending of both empirical and genetic schemes of classification of world climates. In fact, Trewartha's basic aim was to present a simple, generalized and unambiguous scheme of the classification of world climates so that the major climatic types at world level could be easily and realistically identified and cartographically represented on world map. Thus, Trewartha's scheme is a compromise between purely empirical and genetic methods of climatic classification. He was fully convinced that the schemes should not be cumbersome and complex as were the schemes of Koeppen and Thornthwaite. He was also opposed to produce large number of climatic types on the basis of statistical and quantitative parameters. That is why he recognized only a limited number of major climatic types. According to him, if required, several second and third-order subdivisions may be added within each major climatic type. Like other scientists he also made precipitation and temperature as the basis for his scheme of climatic classification. He identified 6 major climatic types of first order at world level and designated them as A, B, C, D, E, F climates out of which B climates were determined on precipitation criteria while others were determined on the basis of temperature criteria.

Tropical Humid Climates (A Climates)

A climates or tropical humid climates are found in those low latitudes on either side of the equator which are characterized by high temperature and adequate rainfall throughout the year and absence of winter season. On the basis of variations in precipitation A climates are subdivided into (i) Af, (ii) Aw, and (iii) Am climates,

(i) Af climate is tropical wet climate which extends upto 5° to 10° latitudes on either side of the equator and is characterized by adequate rainfall throughout the year. This is also known as tropical rainforest climate, There is no winter season as it is characterized by uniformly high temperature all the year round.

(ii) Aw climate is a tropical wet and dry climate characterized by uniformly high temperature throughout the year but there are more than two dry months. This climate is also known as savanna climate which is dominated by dry trade winds or subtropical anticyclones during winter season and by equatorial westerlies and intertropical convergence during summer season.

(iii) Am climate is monsoon climate which receives more than 80 per cent of annual rainfall during four summer monsoon months.

Dry Climates (B Climates)

The boundaries of B (dry) climates have been determined on the basis of precipitation variations. They extend from the outer boundary of A climates to the middle latitudes. B climates are characterized by high evaporation, loss of moisture through evapotranspiration exceeding the annual receipt of water gain from precipitation, large annual and daily ranges of temperature, extreme seasonal temperatures, very low and highly variable annual precipitation, extremely low relative humidity, abundant sunshine and clear sky.

On the basis of aridity and annual average precipitation B (dry) climates have been divided into two climatic types *e.g.*, (i) arid or desert climate– BW climate, and (ii) semi-arid or steppe climate– BS climate. On the basis of temperature variations arid (BW) and semiarid (BS) climates have been divided into 4 climatic types as follows-

(i) BWh climate	tropical-subtropical hot desert climate
(ii) BWk climate	middle latitudes or temperate and boreal cold dry climate
(iii) BSh	climate tropical-subtropical steppe or semiarid climate
(iv) BSk climate	middle latitudes or temperate and boreal steppe climate

The boundary between hot dry and cold dry climates is determined on the basis of 32°F (0°C) isotherm of the coldest month. Tropical-subtropical dry (BWh) and steppe (BSh) climates are dominated by dry trade winds and subtropical anticyclones resulting into constant dry conditions. At least 8 months of a year record average temperature above 10°C. On the other hand, temperate cold dry (BWk) and cold steppe (BSk) climates are located on the leeward sides of the mountains in the interior of the continents and are dominated by cold anticyclones during winter season.

Middle Latitudes Wet Climates (C Climates)

The isotherm of 18°C of the coldest month forms the equatorward boundary of C climates. On the basis of seasonal distribution of precipitation C climates are divided into 3 types *e.g.*, (i) Cs climate (subtropical subhumid climate with dry summer, also known as Mediterranean climate), (ii) Ca climate (subtropical humid climate), and (iii) Cb climate (middle latitude marine climate). Cs climate, located on the western sides of the continents on the tropical margins of the middle latitudes, is affected by subtropical anticyclonic conditions in summers and by wet westerlies in winters. Ca climate (Cfw of Koeppen), located on the eastern sides of the continents, receives precipitation in all seasons but summer months receive more rainfall than winter months (this climate is known as China type of climate). Cb climate is affected by westerlies throughout the year.

Microthermal or Temperate Climates (D Climates)

These climates are found in the areas of high middle latitudes which are affected by westerlies in summers and by polar winds in winters. The poleward and equatorward boundaries are determined by average temperatures of 10°C for 4 months in the case of the former and for 6 months in the case of the latter. On the basis of temperature variations 'D' climates have been divided into 4 types *e.g.*,

(i) Da climate (continental humid climate with temperature of the wannest month above 25°C),

(ii) Db climate (continental humid climate with temperature of the warmest month below 22°C),

(iii) DC climate (subpolar climate, short summer season), and

(iv) Dd climate (temperature of the coldest month less than –38°C).

Boreal Climate (E Climate)

Boreal climate is located in the higher middle latitudes and is characterized by short and cool summer season, long and very cold winter season, very short frost free season, one to three months of a year having average temperature of 10°C or more etc.

Polar Climate (F Climate)

Summer season is absent. Polar winds dominate throughout the year. These climates are found in the northern hemisphere only. No month of the year records average temperature above 10°C. On the basis of temperature variations 'F' climates are divided into (i) tundra climate (Ft climate) and (ii) icecap climate (Ff climate).

Departures From Koeppen's Classification

The Trewartha's scheme of climatic classification registers the following departures from the scheme of Koeppen.

1. In B climates Koeppen used isotherm of 18°C average annual temperature to differentiate the boundary between hot dry and cold dry (h/k boundary) climates while Trewartha used an isotherm of 32°F (0°C) of the coldest month for the determination of h/k boundary.
2. Koeppen used the isotherm of –3°C (26.6°F) temperature of the coldest month for determining boundary between B and C climates while Trewartha selected isotherm of 32°F (0°C) for the purpose.
3. Koeppen divided C climates on the basis of seasonal distribution of precipitation into 3 types *e.g.*, (i) Cs (summers dry), (ii) Cw (winter dry), and (iii) Cf (no dry season) but Trewartha divided C climates into (i) Cs, (ii) Ca, and (iii) Cb types.
4. Koeppen divided D climates on the basis of precipitation into

   (i) Dw, and

   (ii) Df types while Trewartha divided them on the basis of summer temperature into :

   (i) Da, (ii) Db, and (iii) Dd types.

Evaluation

As stated earlier Trewartha's scheme of climatic classification is very simple, unambiguous and a mixture of both empirical and genetic methods of climatic classification. It uses only two weather elements *i.e.*, precipitation and temperature and avoids vigorous statistical and mathematical calculations in determining climatic type of a place and demarcating boundaries between two different climatic types. This scheme also includes the effects of land and water surfaces on the climate of an area. Trewartha's scheme became more popular among geographers because of its simplicity.

KOEPPEN'S CLASSIFICATION

The German botanist and climatologist Wladimir Koeppen presented his descriptive scheme of the classification of world climates first in 1900 based on vegetation zones of French plant physiologist Candolle presented in 1874. He revised his scheme in the year 1918 wherein he paid more attention to monthly and annual averages of temperature and precipitation and their seasonal distribution. He again modified his scheme in 1931 and 1936. Koeppen's original scheme was modified in 1953 by Geigger-Pohl and the revised scheme known as Koeppen-Geigger-Pohl's scheme of classification of world climates was published. It may be pointed out that the classification of Koeppen is more popular because it is quantitative in nature as numerical values of temperature and precipitation have been used in delineation of boundaries of different climatic types. The climates have been named on the basis of alphabets and climates have been determined on the basis of formulae and hence the classification has become difficult to memorise because each alphabet has definite and specific meaning.

Evaluation of Koeppens's Scheme

Koeppen used two easily measurable weather elements *e.g.,* temperature and precipitation as the basis for statistical parameters for the delineation of different climatic regions. In fact, temperature and precipitation are most widely and most frequently used effective weather elements as representatives of the effects of climatic controls. His scheme of climatic classification is primarily based on the relationship between floral types and their characteristics, and climatic characteristics of a given place or a region. He also paid due consideration to the loss of moisture through evaporation as he included effective precipitation, which depends on the rate of potential evapotranspiration, in his scheme. It may be pointed out that it is not the total annual precipitation which matters more for vegetation community rather it is the effective precipitation (amount of precipitation which is actually available to plants) which is more important for flora. Koeppen's scheme appealed more to geographers because the scheme recognized association between vegetation types and climatic types. Besides, this scheme is descriptive, generalized and simple and hence it was widely acclaimed.

Inspite of several merits as referred to above the Koeppen's scheme also suffers from some serious drawbacks. Koeppen gave undue significance to mean monthly values of temperature and precipitation in his scheme of climatic classification and neglected other weather elements such as precipitation intensity, amount of cloudiness and number of rainy days, daily temperature extremes, winds etc. He made his scheme more descriptive and generalized and ignored the consideration of ausative factors of climate. He did not include the characteristics of different airmasses in his classification. The use of different letter symbols to indicate different climatic types and their secondary and tertiary subtypes makes the scheme very difficult to memorise.

Air Pressure And Winds

Thermally induced low pressure belt develops around the equator due to uniformly high temperature throughout the year but the pressure gradient is so low that strong air circulation is not possible. Thus, the equatorial region lies in the belt of calm and doldrums characterized by light and variable winds. The surface air is heated, becomes light and moves upward thus forming convective currents. On the ground surface the winds uniformly spread laterally due to more or less uniform air pressure. The discontinuous belt of doldrum characterized by equatorial westerlies is found along the equator. The convergence of trade winds coming from the subtropical high pressure belt forms inter tropical convergence (ITC) which is associated with atmospheric disturbances (cyclones). The winds become strong with thundestonns. Strong winds give temporary relief from sultry weather. Temperature is lowered due to arrival of Harmattan winds in the nights in the Guinea coast and thus the pleasantly cooling effect of Harmattan gives comfort to human bodies. Sea breezes penetrate upto 48-96 km inland in the coastal areas and thus brings pleasant weather through their cooling effects. This is why coastal areas in the equatorial regions are comparatively better suited for living than the interior areas.

Precipitation

Equatorial regions receive rainfall throughout the year and thus there is no dry season. Average annual rainfall exceeds 200cm to 250cm. Even the driest month of the year receives rainfall more than 6cm. Iquitos (Peru), Akassa and Ocean Island receive 261 cm, 366cm and 213cm of rain per annum respectively. Though most of the rainfall occurs through convective mechanism but wherever mountain barrier becomes effective the amount of rainfall increases substantially.

For example, annual rainfall reaches 1000cm in the foothill zone of Cameroon Mountain in Africa. Most of the annual rainfall in the equatorial region is received in the form of convectional rainfall. The strong daily vertical convective mechanism due to intense heating of ground surface because of high amount of insolation, horizontal convergence of trade winds forming intertropical convergence, a fairly large number of atmospheric disturbances (cyclonic storms) and thunderstorms yield heavy rainfall daily throughout the equatorial regions.

Distribution : Inspite of high rainfall throughout the year there is no uniform spatial distribution of rainfall in all parts of equatorial climatic region. Though no month goes dry but definitely some months of the year receive more rainfall than the other months.

Thus, the months having more rainfall are called wet months while the months receiving less rainfall are known as less wet months. If the temporal distribution of rainfall in the equatorial regions is considered carefully it appears that there are two periods of maximum rainfall and two periods of minimum rainfall in a year. Normally, April and November receive maximum rainfall but the period of maximum rainfall varies spatially. For example, Lagos receives maximum rainfall in May, June and July amounting to 100cm whereas October records 25cm of rainfall.

Cloudiness-equatorial climate is characterized by fairly large amount of cloudiness throughout the year. Generally, cumulus type of clouds dominates daily weather conditions. On an average, there is about 60 per cent cloudiness daily. The maximum amount of cloudiness is found between 3 and 4 P.M. daily because of maximum convective activity during this period but the sky is generally clear in the morning and at night. Though the daily period of cloudiness is less in comparison to high middle latitude areas dominated by temperate cyclones but there is strong heavy downpour due to convective mechanism and resultant convectional rainfall.

Rainfall regime : equatorial rainfall is convectional in character wherein there is daily heavy downpour from cumulonimbus clouds. The sky is usually free from clouds in the early morning. As the sun rises above the horizon, the amount of insolation received at the ground surface increases and hence air temperature also increases accordingly. Air is heated, becomes light and moves upward and thus becomes unstable which causes convectional system. The ascending air cools at the dry adiabatic lapse rate (**10°C** per **1000m**) and the air soon becomes saturated and condensation level is reached. Clouds are formed. In the beginning they are cumulus and few in number but as the day advances, humidity increases due to increasing evaporation, the clouds are thickened and darkness increases. By afternoon the whole sky becomes overcast with thick cumulonimbus clouds. Thus, heavy rain starts with lightning and cloud thunder. As the day draws towards evening the rains become slow and weak and they completely stop by evening, clouds are cleared and weather becomes pleasant for some time. The aforesaid mechanism is repeated daily. Some times, this rhythemic daily mechanism is interrupted as rains continue uninterruptedly for several days. Continuous rains for 40 hours have been reported in Ivory Coast (Africa). The most characteristic feature of equatorial rainfall is that it is usually associated with strong thunderstorms as about 75 to 150 rainy days are associated with them.

Variability of rainfall : inspite of very high mean annual rainfall there is temporal variability in the amount of rainfall and this variability is more than the variability of temperature.

The crops grown in this climatic region are such that they require more moisture and thus the year having little less than average annual rainfall is termed as a drought year because the crops are damaged. Though the word drought is unfamiliar in equatorial climatic region but some times brief drought conditions are created. There is also variability of rainfall within a year. For example, Belem (in the Amazon Basin) receives average annual rainfall of 239 cm and March receives more rainfall than other months. March has 28 rainy days against 10 rainy days in November. It may be concluded that rainfall in equatorial rainforest climate is adequate enough to support field crops and luxurious dense forests. Most of the rains is intercepted by forest canopy and thus reaches ground surface slowly in the form of aerial streamlets through leaves, branches and stems of trees and thus there is maximum infiltration of rainwater. Recent clearance of rainforests in the equatorial regions in general and in Amazonia in particular has converted once forest-converted surface into a bare ground surface which is subjected to accelerated rate of soil erosion due to daily heavy rains.

Effects of Climate On Natural Vegetation

The tropical rainforest or equatorial climatic region accounts for the largest number of plant species and luxuriant growth of natural vegetation due to high temperature and high rainfall throughout the year. The climatic region is characterized by broad-leaf evergreen dense forests comprising valuable trees such as mahogany, rosewood, coconut palm, avony, cincona, plaintain, bamboos, wild rubber, sandal wood etc. The number of tree species is so large and their diversity is so great that one hectare of land in the equatorial region accounts for 40 to 100 species. It may be pointed out that tree species account for 70 per cent of the total plant species of the tropical evergreen forests. Creepers or climbers are the second important members of the rainforests. The creepers comprising (i) climbers of lower strata, (ii) long woody climbers known as 'lianas', and (iii) epiphytes are so circuitous and highly irregular in form that it becomes difficult to find out their actual length. "They ramble through the forest, scaling the highest emergent trees and frequently looping down to the ground and then ascending further sections of the forest" (Furley and Newey, 1983). The climbers so greatly bind several trees and plants together that the accessibility in the forest cover becomes almost zero.

The vertical stratification of vegetation community consists of 5 layers or strata viz. (i) *first* or *top layer* or *dominant layer* representing the canopy of tallest trees (30 to 60m in height), (ii) *second layer* or *co-dominant layer* (25m to 30m in height), (iii) *third layer* of smaller trees (12m to 20m in height), (vi) *fourth layer* of shrubs (5m in height), and (v) *ground layer* of herbaceous plants and ferns.

SAVANNA CLIMATE (AW)

Location

The word savanna has been used for different meanings by various scientists *e.g.*, the word savanna region has been used by the climatologists to indicate a particular type of climate *i.e.*, tropical wet-dry climate (Aw climate of Koeppen) as savanna climate, while the botanists have used the word savanna for a typical type of vegetation community of tropical regions characterized by the dominance of grasses. This climate is also called as Sudan type of climate. Savanna type of climate is located between 5°-20° latitudes on either side of the equator.

Thus, savanna climate is located between equatorial type of climate (Af) and semi-arid and subtropical humid climate. In other words, this climate is located between equatorial low pressure belt or rain producing intertropical convergence and subtropical high pressure belt. The most characteristic areas of savanna climate include the Llanos of Orinico Valley including Columbia and Venezuela, the Guiana Highlands, the Campos of Brazil (south central parts), and Paraguay in South America; hilly areas of Central America; southern gart of Zaire, Angola, Zambia, Mozambique, Tanjania, Uganda, and Central Rhodesia, all to the south of the Congo Basin, and central Nigeria, southern Kenya and Uganda, Central African Republic, Dahomey, Togo, Chad, Ghana, Ivory Coast and eastern Guinea in Africa; northern Australia and some areas of India (the savanna of India is not the original and natural vegetation cover rather it has developed due to human interference with the original forest cover resulting into the development of widespread man-induced grasslands).

Temperature

The Savanna climate is characterized by distinct wet and dry seasons, mean high temperature throughout the year (ranging between 24°C and 27°C), and abundant insolation. Temperature does not fall below 20°C in any month of the year. Thus, Savanna climate is similar to equatorial climate as regards temperature but the annual range of temperature ranging between 3°C and 8°C is greater than in the equatorial climate. There are three main seasons on the basis of the combination of temperature and humidity (though on an average there are only two seasons as referred to in the beginning but the dry season is further divided into warm dry season and cold dry season on the basis of temperature). (1) Cold dry season is characterized by high day temperature ranging between 26°C and 32°C but relatively low temperature during nights, usually 21°C. (2) Warm dry season is characterized by almost vertical sun's rays, high temperature ranging between 32°C and 38°C due to abundant insolation. (3) Warm wet season receives between 80 to 90 per cent of the total annual rainfall and thus records relatively lower temperature than warm dry season.

Air Pressure and Winds

The regions of Savanna climate are affected by low and high pressure systems in a year. Due to northward migration of the sun during summer solstice (21 June) the equatorial low pressure belt and doldurm are shifted northward and thus Savanna climate comes under the influence of *Inter Tropical Convergence* (ITC) which is associated with atmospheric disturbances (cyclones) which yield rains. Due to southward migration of the sun during winter solstice (23 December) Savannaclimatic zone comes under the influence of subtropical high pressure belt and thus anticyclonic conditions dominate the weather and bring dry conditions. The descending stable winds under anticyclonic conditions cause dry conditions. Besides, the coastal areas are affected by local winds and sea breezes. Eastern coasts are influenced by trade winds. Strong and high velocity tropical cyclones dominate the weather conditions during warm season. It is apparent that the Savanna type of climate is induced due to the introduction of wet summer and dry winter seasons because of northward and southward migration of the sun respectively. Since the Savanna climate is located between equatorial wet and tropical dry climates and hence there is gradual variation in weather conditions away from the equator as the aridity increases poleward.

Rainfall

The average annual rainfall ranges between 100cm and 150cm but there is much pronounced variation in the spatial distribution of mean annual rainfall in different parts of Savanna climate mainly because of two factors viz. (1) distance from the equator, and (2) the nature of topographic features. For example, the Savanna region of Brazil, locally called as Cerrado having the average absolute relief of 1300m AMSL, records mean annual temperature and mean annul rainfall of 200C-260C and 75cm-200cm respectively. The Llanos of Columbia is characterized by mean annual rainfall of 200cm-400cm (near Andes Mountain), mean annual temperature of 22°C, and maximum temperature of 32°C. The Indian Savanna is characterized by the highest temperature (being 450C-480C. in May and June) and lowest temperature (being 5°C or even less during the month of January) of all the Savanna regions of the world and the mean annual rainfall well below 150cm, 80 to 90 per cent of which is received during a brief period of 3 months (July to September).

Since the Savanna climate is a transitional belt between humid equatorial and dry tropical climates and hence there is much variability in the amount and duration of rainfall at the wet (equatorward) and dry (poleward) boundaries. There is copious rainfall in the equatorward margins because of convergence of surface winds and convective mechanism of ascending unstable winds but at the poleward margins near dry climate (BWh) is found and rainfall significantly decreases due to descending air and anticyclonic conditions.

Here mean annual rainfall becomes as low as 25 cm. As the Intertropical Convergence (ITC) moves northward due to northward migration of the sun, thunderstorms begin to develop by March and the amount of rainfall increases in the following months.

The Intertropical Convergence reaches its northernmost limit by August. Thus, rainfall continues to increase, upto August and most of rains are received through tropical cyclones and thunderstorms. Rainfall decreases due to southward shifting of ITC and dry trade winds are re-established after November resulting into dry weather condition.

It is apparent that the period of wet weather decreases while that of dry weather increases as the distance from the outer limit of the equatorial climate increases. The amount of mean annual rainfall also decreases from east to west. Savanna climate is also characterized by high variability of rainfall as there may be so heavy and abundant rainfall in a particular year that floods are caused while the following year may receive so little rainfall that drought conditions prevail.

Vegetation

Though, general characteristics of typical Savanna vegetation are trees and grasses but the Savanna Biome is, no doubt, dominated by grasses. The Savanna vegetation community has developed layered structure wherein three distinct layers have clearly developed.

(1) *The ground layer* is dominated by various types of grasses and herbaceous plants, The grasses are generally coarse, stiff and hard having the height ranging between 80cm to 350cm. The African elephant grass attains enormous height of 500cm. The grasses bear deserted look during dry summer season but they become lush green again during humid summer season.

(2) *The middle layer* consists of shrubs and stunted woody plants.

(3) *The canopy layer* is formed by trees of various types. The general characteristics of trees depend on the availability of water and moisture and therefore there is great taxonomic variety of Savanna trees which are usually 6-12m in height. The Savanna trees have

developed various unique characteristics to withstand dry conditions. For example, there are a few species of trees which have developed such mechanisms which help them to reduce evapotranspiration from their leaves during warm dry season and enable them to remain green even during dry season of deficient water supply.

On the other hand, there are such tree species which cannot withstand dry conditions and therefore they shed their leaves and bear the characteristics of deciduous trees. The roots of Savanna trees have also developed according to the environmental conditions as they are very large which can penetrate into the spils and ground upto the depths from 5m to 20m so that they can obtain water from groundwater even during dry season when the groundwater table falls considerably.

The small plants and many herbaceous plants have special kinds of root systems characterized by root tubers and swellings so that they may preserve water which may be used by plants during dry season. On the basis of the proportion of fees and grassland and the structure of vegetation, the Savanna vegetation is divided into 4 types.

(1) *Woodland savanna* is dominated by trees and shrubs and absence of epiphytes but some climbers having their roots in the ground are found.

(2) *Tree savanna* represents relatively open vegetation cover wherein trees and shrubs are sparsely distributed.

(3) *Shrub savanna* is represented by treeless vegetation which is dominated by grasses at the ground layer and shrubs at the second layer,

(4) *Grass savanna* is characterized by general absence of trees and shrubs and overdominance of dense grasses.

Frequent fires, both natural and anthropogenic (deliberate annual burning of grasses by man), are common features of all the savanna biomes. The rapidly increasing human population for the last 50 years or so has put enormous strain on the natural savanna grasslands because a vast area of the original grasslands has been converted into agricultural fields to grow more food crops to feed the teeming millions. Thus, the areas of natural savanna grasslands have shrunk considerably. The savanna ecosystem, thus, has been greatly degraded and destabilized.

MEDITERRANEAN CLIMATE (CS CLIMATE)

Location

The Mediterranean type of climates, climatically known as subtropical dry summer climates, is called Mediterranean type because most of the areas falling under this climate are situated around Mediterranean Sea. The Mediterranean climate or biome is also called as *sclerophyl ecosystem* or *biome* because of the development of special features and characteristics in the dominant trees and shrubs to adapt to the typical environmental conditions of this climate-dry summer and wet winter.

Though, the Mediterranean type of climate covers only 1.7 per cent area of the globe but this is most clearly defined climate and is easily differentiated from other climatic regions. The Mediterranean climate has three distinct characteristics–

(i) Wet winter and dry summer season,

(ii) Warm and hot summers, and mild winters, and

(iii) Abundant sunshine throughout the year (90 per cent in summer and 50 to 60 per cent in winter). This climate has developed between 30°-40° (some times upto 45°) latitudes in both the hemispheres in the western parts of the continents (Fig: 8.5). This climatic region includes

(A) European, Asiatic and African lands bordering the Mediterranean Sea *e.g.*,

(1) European lands—Rhonesaone Valleys of France, southern Italy, Greece;

(2) Asiatic lands-western Turkey, Syria, Lebanon, western Israel;

(3) North coastal Africa—Morocco, northern Algeria and Tunisia and the area north of Bengasi in Lybia;

(B) Central and southern California in the USA,

(C) Central Chile in South America,

(D) The Capetown area of South Africa, and

(E) The coastal zones of southern and south-western Australia. The Mediterranean type of climate owes its origin to the seasonal shifting of wind and pressure belts due to northward (summer solstice) and southward migration (winter solstice) of the sun. Thus, these areas come under the domain of westerlies in winter season. Since the westerlies are moisture laden because they come from over the oceans and are associated with temperate cyclones, they give sufficient rains during winter season. On the other hand, they come under the influence of subtropical high pressure belt and associated anticyclones during summer season and hence there is no rainfall (Fig. 2.1).

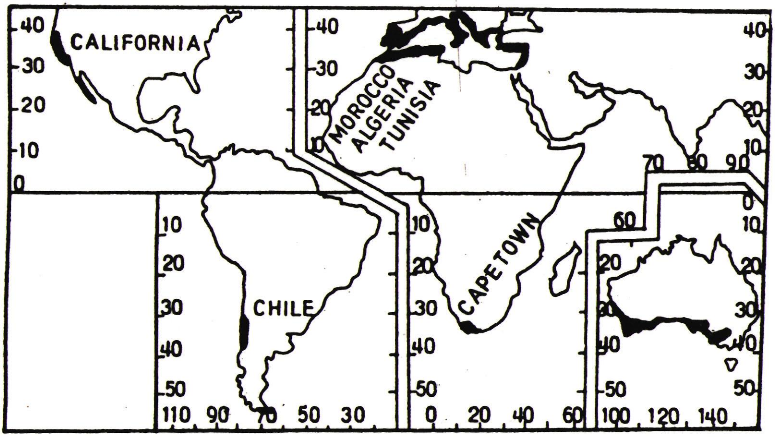

Fig. 2.1 : Spatial Distribution of Mediterranean Climate.

Temperature

The average temperature during cool winter season ranges between 5°C and 10°C whereas mean summer temperature varies from 20°C to 27°C and thus the mean annual range of temperature becomes 15°C to 17°C or even more. In fact, the

Mediterranean climate is considered as a resort climate because of its pleasant and comfortable winter season. The Mediterranean climate whether having coastal or inland location generally records temperature above freezing point during winter season as the average temperature of the coldest month ranges between 4.4°C and 10°C. The mean January temperature is recorded as 7.7°C at Sacramento in California (USA), 6.1°C at Marseille (France), 12.8°C at Perth (Australia) and 6.6°C at Rome. Some times, the temperature becomes so low at nights that frost occurs which is very much injurious to field crops. The valleys and depressions have freezing to subfreezing temperatures in winter and hence valleys are avoided for sensitive crops like citrus fruits which are grown on hill slopes. Los Angeles (California, USA), Naples (Italy) and Sacramento (California, USA) have recorded lowest temperatures of –2.2°C, –1.1°C and –8.3°C respectively.

It may be pointed out that occasional fall of temperature below freezing point is limited to a few minutes to a few hours only. Summer temperature rises above 26°C *e.g.*, Red Bluff of Sacramento valley records 27.5°C whereas average temperatures during summer season are 26.6°C in European Mediterranean lands and 24°C in north-west Africa. It may be mentioned that high summer temperatures are never uncomfortable due to low relative humidity. Daily maximum temperature in summer goes beyond 26°C. For example, the Great Valley of California records daily maximum summer temperatures ranging between 30°C and 32°C. Red Bluff and Sacramento have recorded highest daily maximum temperatures of 45.5°C and 46°C respectively so far. The night temperature during summer season falls to 15.5°C, thus diurnal range of temperature becomes as high as 30°C. Daily and annual ranges increase from coastal areas to inland areas.

On the basis of temperature variations the Mediterranean climate is divided into 2 subtypes *e.g.*, Csa and Csb. Csa climate, characterized by hot summer, has inland location whereas Csb climate of mild summer is located along the coastal margins of the continents. It may be pointed out that temperatures of the Mediterranean climatic regions except those around Mediterranean Sea are largely affected by cool oceanic currents *e.g.*, Califomian region by cool California current, Chilean region by cool Peru current. Cape Town region by Benguela currents etc.,

Air Procure and Winds

In fact, the Mediterranean climate is the outcome of the seasonal shifting of pressure and wind belts. All the pressure belts except polar high pressure belt move northward from their normal positions during northern summer (summer solstice when the sun becomes vertical over the tropic of Cancer on June 21) and thus subtropical high pressure system extends over the regions of Mediterranean climate (30°N to 40°N) and anticyclonic conditions dominate the weather conditions causing subsidence of air from above, horizontal divergence of surface winds, stability of air resulting into dry conditions. Sirocco local hot winds blow from Sahara northward picking red sands which are brought to Italy, Spain, southern France and Greece. Summer winds are generally hot and dry. These areas come under the domain of westerlies during winter season when the sun moves southward (northern winter). The westerlies are associated with temperate cyclones originating in the middle latitudes. Since the westerlies are associated with temperate cyclones and come from over sea surfaces and hence being moist give sufficient rainfall in the coastal areas. Some local winds like Bora. Mistral (cold winds) etc. affect the local weather conditions of the European Mediterranean lands during winters.

Precipitation

The mean annual rainfall ranges between 37 cm and 65 cm, the most portion of which (more than 75 per cent) is received during winter season mainly between December and March in the northern Hemisphere and between May to September in the southern hemisphere. The winter rainfall is received through cyclonic storms associated with moist westerlies. The summer season is almost dry. Because of moderate to scanty rainfall the Mediterranean climate is called as subhumid climate. The orographic rainfall is common in those coastal areas (*e.g.*, California) which are backed by mountain ranges parallel to the coasts. Though winter season is quite wet but the sky is seldom overcast for longer duration in continuation and thus abundant sunshine is available even during wet winter season. For example. Red Bluff (California, USA) has only 11, 12, 10 and 10 rainy days in December, January, February and March respectively. January is the rainiest month in San Bernardino and Los Angeles but there are only 7 rainy days. January being the coldest month of Red Bluff receives 11.5 cm of rainfall while July being the coldest month of Perth (Australia) receives 16 cm of rainfall. All these indicate the intensity of rainfall during winter months in the Mediterranean climatic regions. Summer season is characterized by scanty rainfall, almost dry weather, clear skies, and bring sunshine. Besides temporal variation, there is also spatial variation of rainfall. Generally, the amount of rainfall increases from south (24 cm at San Deigo, 29cm at Los Angeles) to north (58 cm at Sansfransisco) in California.

The seasonal regime of rainfall causes fluctuations in the soil-water and soil-moisture regimes during winter and summer seasons. The amount of soil-water increases during winter season because of winter and spring rainfall which is responsible for maximum growth in vegetation but dry .summer season causes deficiency in the soil-water content because of loss of water and moisture due to increased evaporation and evapotranspiration because of substantial increase in temperature and of course due to general lack of rainfall during summer season.

Natural Vegetation

Though the Mediterranean regions are widely scattered over different continents, there is more or less broad generalization in the overall structure and composition of vegetation community of all the regions of Mediterranean biome. The structure of Mediterranean vegetations is such that they can withstand the aridity of summer season. Consequently, the leaves have developed sclerophyllous characteristics in that they are stiff and hard and the stems have thick barks. The Mediterranean vegetation community consists of a variety of sclerophyll plant formation classes which range from Mediterranean mixed evergreen forests (in the coastal lands immediately bordering the areas and the oceans) to woodland, dwarf forest and scrubs. The vegetation community is dominated by trees and shrubs. The shrubs are differently named in various parts of the Mediterranean biome on the basis of local names *e.g.*, maquis or garigue in southern Europe, chaparral in California, fymbos or tymbosch in South Africa, and malice scrub in Australia.

The xeromorphic structure such as thickened suiticles, grandular hairs, sunken stomata etc. enables the plants to withstand dry conditions. The sclerophyllous structure of plant leaves enables them to regulate the gaseous exchange according to the availability or scarcity of water during different seasons of the year. The plants have also developed special types of root systems in accordance with the regional environmental conditions mainly the availability of moisture.

The European Mediterranean regions are characterized by multi-layered structural pattern of vegetation community consisting of (i) topmost layer of evergreen and deciduous oak trees. (ii) middle layer of shrubs locally called as maquis or garigue, and (iii) the ground layer of numerous herbaceous plants. The Californian Mediterranean lands are characterized by the (i) topmost layer of oak trees, (ii) the middle layer of chaparrals, equivalent to European maquis, and (iii) the ground layer of herbaceous plants and grasses. The South African Mediterranean Biome is characterized by attractive flowering plants of numerous varieties *e.g.*, Erica, Ereesia, Lobellia, Kniphofia species etc. The shrubs are locally called as *fymbos.* The Australian Mediterranean Biome is characterized by numerous species of eucalyptus. Fire, both natural and man-included, is normally an annual occurrence in the Mediterranean climatic regions. Burning, mass clearance of natural vegetation for agricultural and commercial purposes, overgrazing of grasslands etc. have led to accelerated rate of soil erosion, increase in the silt load of major rivers and transformation of original natural vegetation.

CHINA TYPE OF CLIMATE (CA)

(Subtropical Humid Climate)

China type of climate, climatologically known as subtropical humid climate, is characterized by hot summer, mild to cold winters, spatial variations in temperature, humility and precipitation and is located between 20°-400 latitudes in both the hemispheres along the eastern parts of the continents (Fig. 2.2). This climatic region is flanked by inland dry regions in the west (except in Po and Danube basins), by monsoon climatic areas in the south, by humid continental climate in the north, and by oceans in the east. The subtropical humid climate (Ca) is found in the following regions-south-east and south China (south of Yellow river); Po Basin; Danube Basin; south-eastern USA; south-eastern Brazil, Paraguay, Uruguay and north-eastern Argentina; south-eastern Africa; and east coast of Australia.

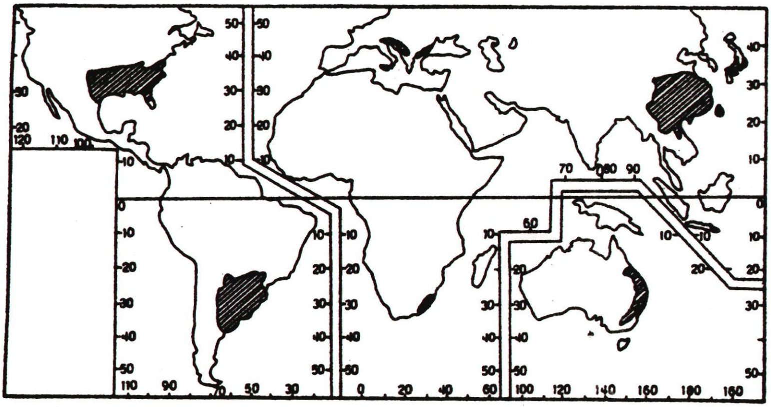

Fig. 2.2 : Distribution of China type of climate.

It is apparent that Mediterranean type and China type of climates are found in the same latitudinal locations but are differentiated on the following counts-(i) Mediterranean climate is found in the western parts of the continents while China type of climate is located along the eastern coastal areas of the continents, (ii) Mediterranean climate is characterized by wet winter and dry summer whereas in China type of climate summer season receives maximum rainfall though rainfall is received throughout the year. (iii) Mean annual rainfall is higher in China type of climate than Mediterranean climate. China type of climate is also called as sub monsoon climate because of its near similarity with monsoon climate.

Temperature

The coastal parts of China type of climate are frequented by warm oceanic currents (*e.g.*, warm Gulf Stream off the east coast of the USA, warm Brazil current along the east coast of South America, warm east Australia current off the east coast of Australia, Kuro Shio current off the coast of China, and Mozambique current along the south-east coast of Africa) and thus these warm currents affect the temperature of coastal areas. The mean summer temperature ranges between 24°C and 26.6°C. The month of July records mean temperature of 28°C at Charlston (South Carolina, USA) and Montgomery (Alabama, USA), 27.2°C at Shanghai whereas January, the wannest month in the southern hemisphere, records mean temperature of 25°C at Brisbane (Australia) and Durban (Africa), and 23.3°C at Buenos Aires (South America). Daily maximum temperature crosses 37.7°C (100°F). For example, maximum daily temperature at Montgomery is recorded as 41°C in July and 41.6°C in August. Similarly, Savannah of Georgia (USA) has recorded 41°C as maximum daytime temperature in July. It may be pointed out that high summer temperature is also associated with high relative humidity and hence the weather becomes uncomfortable.

The loss of the heat during nights through outgoing longwave radiation is retarded because of cloudiness and hence temperature does not fall appreciably at nights resulting into low diurnal range of temperature. For example, the mean maximum and mean minimum temperatures of Montgomery (Alabama, USA) are 32.8°C and 22.2°C respectively and thus diurnal range of temperature becomes 11.6°C.

Generally, winters are mild as mean temperature ranges between 6.6°C and 10°C. Mean winter temperature is recorded as 9.4°C at Montgomery (Alabama, USA), 3.3°C at Shanghai, 10°C at Buenos Aires, 11.7°C at New Orleans (USA), 6.1°C at Nagasaki, and 11°C at Sydney. Mean annual range of temperature in China type of climate is not large but is marked by wide range of spatial variations. For example, mean annual range of temperature is 12.8°C at Buenos Aires and Sydney, 10.5°C at Montgomery and 24°C at Shanghai. In fact, annual range of temperature is controlled by the extent of land areas and the strength of winter monsoon winds. The more extensive the land areas and stronger the winter monsoon, the larger is the annual range of temperature.

The arrival of cold polar winds during winter season causes temperature to fall below freezing point. For example, in the absence of any mountain barrier from west to east in North America, the extremely cold continental polar airmass invades the whole of the plains of the USA and reaches the Gulf Coastal plains of the country and thus the temperature falls below freezing point (about –12°C) in the Gulf Coastal state of the southern USA during winter season.

Air Pressure and Winds

The continental and oceanic areas are characterized by low and high pressure systems during summer season, with the result monsoons are developed. Thus, tropical maritime airmass (mT) develops over land areas falling in Ca climate mainly over China and southeastern USA. This air mass is south-easterly in the northern hemisphere while it is north-easterly in the southern hemisphere (during summer season).

High pressure systems develop over south-western and northern central Pacific Ocean and near Azores in the Atlantic Ocean. These tropical maritime airmasses are also associated with tropical cyclones which yield sufficient rainfall. These tropical cyclones are called typhoons in China, hurricanes in the USA and southern busters in Australia.

The pressure system is reversed during winter season as high pressure develops over continental areas while oceanic areas are characterized by low pressure systems. Thus, the winds become offshore. This is the reason that the coastal areas of the eastern and south-eastern USA are not much benefitted from the warm Gulf Stream because the winds are offshore.

Precipitation

Though, average annual precipitation in subtropical humid climate (Ca) ranges between 75 cm and 150cm and some times it becomes as much high as 250 cm in some favoured locations but there is wide range of variation in the seasonal and spatial distribution of annual rainfall. Generally, rainfall decreases from coastal areas to the inland locations. On the basis of seasonal distribution of rainfall this climate is divided into two subtypes *e.g.*, (i) Caf climate having rainfall throughout the year, and (ii) Cw climate having dry season during winter.

On an average, the summer rainfall in China type of climate is definitely abundant and exceeds evapotranspiration. The summer rainfall is received through cumulus clouds resulting from convective currents caused by intense local heating of the ground surface. Besides, tropical cyclones (*e.g.*, typhoons in China and hurricanes and tornadoes in the USA) also yield heavy downpour with cloud thunder and lightning. The Gulf coastal states of the USA are generally frequented by large number of thunderstorms. For example, Florida experiences at least 60-thunderstorms each year.

These thunderstorms are associated with unstable tropical maritime air mass. The summer rainfall in China and Japan is divided into three types of regime viz. (i) maximum rainfall period of early summer season, (ii) maximum rainfall period of late summer season, and (iii) minimum rainfall period of middle summer season. Some times, the rainfall occurring from hurricanes in the south-east USA and from typhoons in China is so heavy that catastrophic floods are caused.

Hurricanes very often strike the southern and south-eastern coasts of the USA. The Gulf coasts of Louisiana, Texas, Alabama and Florida are worst affected areas. The Galveston, Texas (USA) disaster of September 8, 1900 tells the story of devastation caused by hurricane in Gulf coastal states of the

USA. The terrible hurricane generated a strong storm surge (tidal wave) which raced inland and killed 6000 people mostly through drowning caused by inundation under 3 to 4.5m deep water.

Winter rainfall is generally received through winter cyclones which are associated with the westerlies. Though the duration of individual rainstorm during winter season is much longer but total rainfall is comparatively less. It may be pointed out that inspite of less rainfall during winter season there is more cloudiness and larger number of rainy days than during rainier summer season. For example, 5 cm of January rainfall of Shanghai is received within 12 days whereas 15 cm of August rainfall is received in only 11 days. Some times, there is occasional frost and snowfall during winter season.

Natural Vegetation

The China type of climate characterized by abundant rainfall, high temperature and long growing season of 7 to 12 months favours luxuriant growth of natural vegetation. Dense forests of evergreen nature are found in more humid areas but areas of moderate rainfall are characterized by deciduous sparse forests and grasslands. Normally, mixed forests of coniferous trees and broad leaf trees are found. The broad-leaved forests are both evergreen and deciduous depending on the spatial variation of distribution of annual rainfall.

STEPPE CLIMATE (BSK)

Location

The middle latitude steppe climate (BSk) spread over temperate grasslands is located in the interiors of the continents which come in the westerly wind belt but because of their more interior locations they do not get sufficient rainfall and hence the grasslands are practically treeless. The temperate grassland steppes of the southern hemisphere are located along the south-eastern margins of the continents (Fig 8.7) and therefore have more moderate climate than their counterparts of the northern hemisphere because of more marine influences as they are closer to marine environments.

The temperate grasslands of Eurasia, known as steppes, are most extensive as they extend for a distance of more than 3200 km from the shores of the Black Sea across the Great Russian Plain to the foothills of the Altai Moutanins. Their continuity is broken at few places by the highlands. There are also some isolated patches of steppes *e.g.,* in Hungry (known as *Pustaz*) and in the plains of Manchuria (Manchurain Grassland). The temperate grasslands in North America (extending in Canada and USA both) are locally known as *prairies* which extend from the foothills of the Rockies in the west to the temperate deciduous forest biome in the east.

The temperate grasslands of the southern hemisphere include the *pampas* of Argentina and Uruguay of South America, *bush veld* and *high veld* of South Africa, and downs of the Murray-Darling Basins of southeastern Australia and *Canterbury grasslands* of New Zealand (Fig. 2.3).

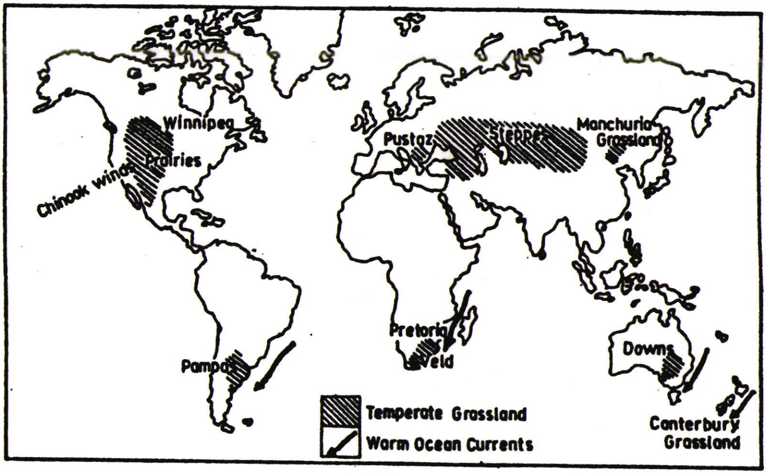
Winnipeg
Prairies
Chinook winds
Pustaz
Steppes
Manchuria Grassland
Pretoria
Veld
Pampas
Downs
Temperate Grassland
Warm Ocean Currents
Canterbury Grassland

Fig. 2.3 : Spatial distribution of temperate steppe or grassland climate.

Temperature

The temperate steppes are characterized by continental climate wherein extremes of summer and winter temperatures are well marked but the temperate grasslands of the southern hemisphere are marked by more moderate climate. Summers are warm with over 20°C temperature in July (Winnipeg, Canada) and over 22°C in January (Petoria, South Africa, January is summer month in the southern hemisphere). Winter season becomes very cold in the northern hemisphere because of enormous distances of temperate grasslands from the nearest sea. Winnipeg records –20°C in January. The average temperatures during winter season for Tashkent (Uzbeck Republic) and Semipalatinsk (Kazakh Republic) are 0°C and –12°C respectively. The steppe climate of the southern hemisphere is never severe rather it is moderate because of nearness to the sea. The average winter temperature ranges between 1°C and 12°C in the southern hemisphere.

The steppe climate is characterized by high annual range of temperature. For example, Winnipeg (Canada) records mean annual range of 40°C. Laramine (Wyoming state in USA) records annual range of 23.4°C (–6.7°C in "January and 16.7°C in July). Due to marine influences the mean annual range of temperature in the southern hemisphere is much lower than the northern hemisphere as it is around 10°C to 12°C only. Diurnal range of temperature is also very high in the temperate steppe climate.

Precipitation

The mean annual precipitation ranges between 25 cm to 75 cm in different locations of the temperate grassland steppe areas. The winter precipitation in the northern hemisphere is usually received in the form of snowfall and most parts of Eurasian steppes are snow-covered for several months during northern winters. Most of the annual rainfall is received during summer season.

Regional Characteristics

The Eurasian steppe climate covers the largest area in the former Soviet Union (now the Commonwealth of Independent States-CIS and other Republics of former USSR) wherein it extends from eastern Europe to western Siberia and between temperate coniferous forests in the north and arid regions in the south-west. The Eurasian steppes are divided into (i) forest steppe, and (ii) grass steppe wherein the former receives mean annual precipitation of 50 cm to 60 cm whereas the latter receives 40 cm to 50cm as mean annual precipitation. The following sequences of vegetation communities are found from north to south :

(1) Forest steppe (consisting of oak, elms, limes, mapple, a few arboreal vegetation of Siberian Steppe such as birch with mixture of aspen and willow),

(2) Meadow steppe (consisting of the species of turf grasses such as stipa and Fescue and numerous herbaceous flowering plants such as numerous herbaceous flower plants such as Trifolium and several types of daisy,

(3) Grass steppe (consisting of grasses mainly tussock-forming species of Stipa, a few flowering xerophytic shruby species of Artemisia,

(4) Semi-arid xeromorphic steppe dominated by xerophytic grasses such as Fescue and feather grass species, (mean annual precipitation ranging between 30 cm to 35 cm).

The North American Prairie has developed in the USA and Canada between the foothills of the Rockies in the west and temperate deciduous forest biome in the east. On the basis of decreasing trend of mean annual precipitation from east (105 cm) to west (40 cm) the North American Prairies are divided into 3 subregions *e.g.,* (1) tall grass prairie (most dominant species of tallest grass are Bluestem and Switch Grass which attain the height of 1.5m to 2m, few patches of oak and hickory trees are also found), (2) mixed prairie (most extensive cover in the Great Plains of the USA, mixture of medium grasses, 0.6 to 1.5m in height, and short grasses such as little bluestem, needle grass-Stipa spartea, June grass and short and bunch grasses such as buffalo grass and blue gramma, and (3) short grass prairie (developed over western part of the Great Plains and dominated by short grasses of 60 cm height).

The South American Pampas are developed over 12 per cent area of Argentina and are more humid than Eurasian steppes. The mean annual precipitation decreases from east (coastal land, 90 cm) to west (45 cm). Thus, the Pampas are divided into two sub-types *e.g.,*

(i) Humid Pampa, and

(ii) Subhumid Pampa.

The humid Pampa, developed in the eastern part of Argentina, is characterized by tall grasses whereas increasing aridity westward results in the growth of short grasses in the western sub-humid Pampa.

The African veld has developed on the high plateau land of varying heights (1500m to 2000 m) in the south-eastern part of South Africa. The African Velds include the temperate grasslands of southern Transwall and Orange Free State of South Africa and some parts of Lisotho. Plant growth is not possible because of uncertainty of rainfall, increasing aridity, severity of frosts during nights and high daily range of temperature during winter season and thus true climax grasslands of African Velds have developed.

The Australian downs have developed in the south-eastern parts of Australia and in the northern part of Tasmania. The region is characterized by (i) relatively warmer winter season than the temperate grasslands of the northern hemisphere, and (ii) mixture of grasses with eucalyptus trees. The grasslands gradually change from south (Australian coast) to north (interior land) in accordance with the decreasing trend of mean annual precipitation from south (152 cm) to north (63.5 cm). The region is further divided into distinct 3 subregions *e.g.,* (1) temperate tall grasslands, (2) temperate short grasslands, and (3) xerophytic grasslands.

WEST EUROPEAN TYPE OF CLIMATE (CB)

Location

West European type of climate (Cb) also known as *marine west coast climate* is located between 40° and 65° latitudes in both the hemispheres along the western coasts of the continents. This climatic region is surrounded by Mediterranean climate in the south, continental dry climate in the east and semi-arctic climate in the north. The inland extension of this climate is controlled by topographic features. For example, wherever the coast is paralleled by mountain ranges, this climate is found in a very narrow coastal belt *e.g.,* marine west coast climate is confined to the coastal strips along the western coasts of North and South Americas because of Rockies and Andes.

On the other hand, wherever relief barrier does not exist, marine influences reach far inland *e.g.,* north-western Europe. Thus, the west European type of climate has developed over north-western Europe (including Great Britain, western Norway, Denmark, northwest Germany, Netherlands, Belgium, Luxemberg, and north-western France), British Columbia of Canada, Washington and Oregon states of the USA, south-west coast of Chile (S. America), south-east coast of Australia, and Tasmania and New Zealand.

Temperature

The temperatures, in the west European climate are affected by marine influences, warm ocean currents and prevailing winds and air masses. In fact, the moderating effects of sea bring down the difference between summer and winter seasons considerably. This climate is characterized by cool summer and mild winters. Average temperature during summer season ranges between 15°C and 21°C. Thus, the summer months are characterized by negative thermal anomaly *i.e.*, the coastal regions in the marine west coast climate record relatively lower temperature during summer season than the average temperature for their latitudes. There is very negligible variation in the spatial distribution of temperature during summer season as it is indicated by mean July temperature of the following stations – 17°C at Seattle (USA), 14.4°C at Bergen (Norway), 15.6°C at Dublin (Ireland), and 19°C at Paris (Prance). The daily minimum temperatures in July at Seattle and Bellingham (Wales) are 12.8°C and 10.6°C respectively while daily maxima at these stations are 22.8°C and 21.7°C respectively. Thus, diurnal range of temperature in July for Seattle and Bellingham becomes 10.0°C and 11.1°C. Some times, daytime summer temperature exceptionally rises to 32°C-38°C.

Winters are exceptionally milder for their latitudes due to proximity of warm ocean currents and thus the coastal locations of western Europe are characterized by positive thermal anomaly *i.e.*, they record higher temperature than the average temperature of their respective latitudes due to the influence of warm North Atlantic Drift (extension of warm Gulf Steam). The positive thermal anomaly of 11°C to 17°C is a common feature. The winter temperature decreases rapidly from the coasts towards the interior parts in Europe due to decreasing marine influence inland. This is why the January isotherms instead of following latitudes become parallel to the coasts. The mean January temperature in coastal areas of N.W. Europe ranges between 4°C and 10°C but it becomes –18°C to –40°C in the interior continental locations of Eurasia. The night temperature generally falls below freezing point and hence ground frost is of very common occurrence. Cold waves are generated due to arrival of cold continental polar air masses.

The marine west coast climate comes under the domain of westerlies which are regular features throughout the year. Since these winds come from over the oceans and hence they are moist and give precipitation. These westerlies are also associated with temperate cyclones which are the main sources of precipitation. The poleward margins are dominated by subpolar low pressure belt of dynamic origin where unstable polar front is formed due to convergence of two contrasting air masses *e.g.*, warm and moist westerlies and cold polar air mass. This polar front thus causes the development of temperate cyclones which move in easterly direction under the influence of westerlies.

Precipitation

Marine coast climate or West European type of climate is basically humid climate and is characterized by abundant and uniformly distributed precipitation throughout the year cut winter maximum is the characteristic feature of coastal locations while interior locations record summer maximum. Inspite of abundant precipitation all the year round there is much spatial variation in its amount. Generally, precipitation decreases from the coasts towards interior locations and from north to south along the coast. The regional distribution of precipitation is highly controlled by topographic factor. The areas of low reliefs receive relatively low precipitation. For example, the north-western European lowland in the absence of any effective relief barrier receives mean annual precipitation ranging between 50 cm and 75 cm. On the other hand, the western coastal areas of North America and of Chile in South America falling under marine west coast climate receive high mean annual precipitation ranging between 250 cm and 375 cm because of the presence of the coast range mountains in North America (parallel to the coast) and the Andes in South America (parallel to the coast). The leeward slopes of these mountains become dry because of very low precipitation as they fall in rainshadow region.

Though the precipitation is uniformly distributed throughout the year but winter season receives more than the summer season, but there is no dry month. These conditions are confined only to the coastal location because interior locations receive more precipitation in summers than in winters. The precipitation in low land areas (plains) is cyclonic in nature and is usually received in the form of drizzles and continues for fairly long time. Sky remains overcast for several days in continuation. The winter cyclonic precipitation is very widespread. The summer precipitation is of short duration but is stormy and heavy. The 6 cm July precipitation of London is received in 13 days while 5.3cm January precipitation comes in 15 days. The thunderstorms are very few in number.

It is interesting to note that though the mean annual rainfall is moderate but it is received in large number of rainy days. For example, the mean annual precipitation of 56.5 cm of Paris is received in 188 rainy days while London gets mean annual precipitation of 71.3 cm in 164 days. The percentage of cloudiness is also much higher in this climate *e.g.*, the Pacific coastal areas of N. America record average annual cloudiness between 60-70 per cent while it is 70 per cent in the western Europe. Winter months are also characterized by snowfall but the number of days receiving snowfall is less than in other climates located within the same latitudes. The snow days in London, Paris and Seattle (representing low land location) are 13, 14 and 10 respectively. The frequency of snow-days and intensity of snowfall both increases poleward and towards interior locations.

Natural Vegetation

The abundant precipitation throughout the year has given birth to dense forests of three types *e.g.*,

(i) broad-leaf deciduous forest (oak, birch, walnut, maple, elm, chestnut etc.),

(ii) needle-leaf (coniferous) forest (pine, fir, spruce etc.), and

(iii) mixed forest but cleared in British Isles and European countries due to urban and agricultural development.

Dense forests are now found only on mountains and highlands. Douglas fir, redwood, hemlock, spruce, cedar etc. soft wood forests of much commercial use are found in the states of Washington, and Oregon of the USA and British Columbia of Canada.

GENERAL FEATURES OF CLIMATES

Climate directly affects the daily life of every person on the earth's surface, and forms an important feature of the environment. There is admittedly much controversy concerning the relationship between climate and racial characteristics, but no one can deny that some relationship does exist.

Climate helps to determine food, clothing, housing and general mode of life; its effects encourage or discourage the diseases and pests to which man is exposed in various parts of the world. The trade routes which opened up the world in sailing-ship days were controlled to a large extent by air currents, which in the air age are still important. Moreover, climate affects other features of the environment. Climatic elements are largely responsible for the detailed sculpture of the face of the earth—weathering, the work of running water and of glaciation, wind and water action in desert lands, even the storm-waves which pound the coasts, are all the results of climate. The mantles of soil and vegetation, both natural and cultivated, owe much of their character to their climatic environment.

Climatic Changes

The various climates of the world today differ considerably from those in the past. Many parts seem to have experienced both 'warm periods' and 'cold periods' (commonly called 'Ice Ages'), and also 'arid periods' and 'pluviose periods', as has been determined from such geological evidence as the nature of the rocks themselves and the character of the remains, plant and animal, found therein.

The general distinction between Pole and Equator seems to have obtained for a very long time, but at times polar influences extended equatorward, at others the reverse took place. A mid-latitude location, such as the British Isles, has experienced a succession of changes—a tropical climate in the Carboniferous period, a desert climate in the Triassic, a cool temperate climate in the Cretaceous, and an arctic climate in the Quaternary, succeeded by minor fluctuations in postglacial times.

These climatic changes are not limited to long-distant geological time. A fascinating line of research is the tracing of climatic changes within historical times by piecing together evidence from a variety of sources, many items scanty in themselves but often supplementing and corroborating some other information. There is much evidence of ruined settlements in what is now desert, of ancient irrigation works, of shrinking glaciers, of the width of the annual growth rings in trees (dendrochronology), and of both legends and eyewitness records of floods, droughts and great frosts. One example of such evidence is the discovery of coffins in Greenland, exhumed from what is now permanently frozen terrain, yet with remains of tree roots penetrating the coffins. When all the available evidence is analysed and put together with care, a climatic time-chart for the last few thousand years can be constructed.

CLIMATOLOGY AND METEOROLOGY

Weather and Climate

The term weather is used to describe the condition of the atmosphere at a certain place at some specific time; it is essentially a day-to-day, or even an hour-to-hour, phenomenon. Climate comprises a description of the condition of the atmosphere over a considerable area for a long time. Thirty-five years was usually considered to be the minimum period of time which must elapse before an adequate summary of a particular climate can be made. In some parts of the world this 'climate' is harder to describe in average terms than others; thus it is sometimes said that the British Isles experience weather rather than climate.

Climatology The science of climatology falls largely within the province of the geographer, since it involves an analysis of the spatial distribution of atmospheric phenomena. A climate has been called a 'geographical entity', and much of the work of the climatologist lies in defining and describing different climates in their geographical settings. The terms 'climate' and 'climatic type' are commonly used synonymously. Climatology is in part descriptive, presenting an actual survey of pressure, temperature, rainfall and the other elements, but it must to some extent be explanatory as well. Here, then, the geographer comes into contact with meteorology, and he has realized in recent years that he must draw more and more from this science to assist his understanding of the climatic elements, hence the terms 'synoptic' and 'dynamic' climatology, whereby the subject is studied from the view-point of its relationship to the pattern of atmospheric energy transfer and exchange, of heat and water balances, and of the general circulation of the atmosphere.

Meteorology

Meteorology is the scientific study of the physical processes constantly at work in the atmosphere. Modern meteorology is to a large extent the field of the mathematical physicist, for a training in thermodynamics and hydrodynamics is essential if atmospheric processes are to be fully understood. One function of meteorology is its application to the forecasting of the future trend of the weather, a development of vital importance in this age of aviation. The basis of conventional forecasting is the construction of synoptic charts from simultaneous observations of atmospheric phenomena at a number of stations. Modern developments include mathematical forecasting, using a computer to solve sets of 'forecasting equations'; the recognition of periodicities and singularities', and in long-range forecasting the use of analogues, that is, the deduction of a series of future repeating patterns of weather situations by analysing and comparing sequences of past years.

More important from the point of view of the climatologist is the contribution of scientific method and explanation which meteorology makes to his descriptive distributions. The analytical study of individual masses of air with distinctive features of temperature and humidity, and of the conditions of the upper air, have both yielded much information which the geographer can use to assist his climatological descriptions.

The data of climatology are provided by stations which have recorded temperature, pressure, wind, rainfall and the other elements over a period of years. In western Europe and eastern North America there is a reasonably close network of such stations, elsewhere they are much more sporadic; there are about 2500 stations in the northern hemisphere.

There are many parts of the land-masses (and much of the oceans) for which there are only short-term records or none at all; much of the work of the climatoologist, in describing climatic types, must be in the form of cautious deductions from general principles and short-term observations. In recent years, knowledge of oceanic meteorology has been substantially increased by the systematic compilation of records by permanently stationed 'weather-ships', maintained by the U.S.A., Great Britain, Norway and other European countries in the eastern Atlantic, and by flights of specially equipped aircraft, such as the Research Flight for the Meteorological Office. Numerous weather-satellites in orbit now transmit continuous information.

In January, 1967 a high-speed weather communication link was opened between North America and western Europe, transmitting information from satellites in orbit. This link forms part of the World Weather Watch established by the World Meteorological Organization, with its headquarters in Geneva, which began operation in 1968. The heart of the system consists of three centres at Suitland (Maryland, U.S.A.), Moscow and Melbourne, the clearing houses for vast bodies of statistical information concerning world weather patterns from sea-level to about 30 km (20 miles) in altitude. The whole essence of this elaborate organization is based on the development of three techniques: high-speed long distance communication links, electronic computers and orbiting satellites providing not only photographs of changing cloud patterns but also vast quantities of data for computer processing.

'LOCAL CLIMATE' AND MICROCLIMATOLOGY

In recent years there has been considerable development in the detailed study of 'local climates'. This involves the careful examination of slight, yet significant, contrasts in climate that may result from small differences of slope and of aspect, from the colour and texture of the soils, from the proximity of water surfaces, from the nature of the vegetation cover, and from the effects of buildings.

Its application involves the appreciation of the significance of these small climatic variations for plants, animals, insects and human beings. The vital question of frost incidence, for example, has occupied the attention of climatologists and horticulturists alike. Various lines of research include the routes taken by the downward creep of cold air, the position of 'frost pockets', and the creation of 'frost-breaks' in the form of thick hedges. There has been much research into urban climates—the study of the interference of buildings with air movement, the questions of atmospheric pollution and of fog occurrence, and the degree of warming of the mass of air resting in and above a city (*e.g.*,, London's 'heat-island'). The siting of new towns, villages and airports calls for detailed preliminary work in this field. This mainly involves the recording of the temperature of the air layer, a few metres thick, resting on the ground, and includes records of soil temperature at certain depths.

A distinction is made between the study of a 'local climate', that is, the climate of a small area, and of a 'microclimate', that is, the detailed and very small-scale study of meteorological conditions within natural and cultivated vegetation, principally from an ecological point of view. A further term now employed, logically enough, is micrometeorology, which implies the detailed scientific study of the lowest layer of the atmosphere.

CLIMATIC FACTORS AND ELEMENTS

The term *climatic element* is a convenient label for each of the constituents which make up the sum total of climate—temperature, air pressure, wind, humidity and precipitation. These elements result from the interplay of a number of *factors or controls*, that is, determining causes. In the description of each element which follows, the applicable determining factors are also considered. Several factors appear over and over again.

Latitude is an important factor, since it determines both the length of day throughout the year and the intensity and possible duration of sunlight received. Altitude has very definite results on temperature, pressure and precipitation, and mountain ranges sometimes form clearly defined climatic barriers and therefore boundaries of climatic types. The distribution of land and sea is a third factor; 'continental' and 'marine' influences can be very important. Ocean currents exercise cooling or warming effects on the margins of the land-masses near which they flow if onshore winds blow over them. Of more local importance are the presence of large lakes, the influence of *physical features* involving differences in aspect, shelter from or exposure to cold winds, the presence of deep valleys and basins, and the influence of *soils* and *vegetation*.

THE ATMOSPHERE

The atmosphere is a thin layer of gas held to the earth by gravitational attraction, three-quarters of which lies within 11 km (7 miles) of the earth's surface, 90 per cent within 16 km (10 miles) and as much as 97 per cent within 27 km (17 miles). The 'weathermaking' layers are limited to a height of a few km, particularly as a large proportion of the water-vapour is contained in the lowest 3000 m (10,000 ft); more than half, in fact, is below 2300 m (7500 ft).

In recent years much research has been carried on into the physical conditions of the upper air. The *balloons-sondes*, carrying self-recording instruments, have been gradually replaced by *radiosondes*: radio transmitters, giving out signals indicating changes in pressure, temperature and humidity, are borne by balloons to a height of 18,000-30,000 m (60,000-100,000 ft), when they burst. The rawinsonde (an abbreviation for 'radar wind-sounding') carries a radar target enabling the -course of the balloon to be followed directly and so the upper air currents to be measured.

More recently much information has been obtained by means of rockets and orbiting satellites. Observations thus derived may be plotted in various ways. Their interpretation can reveal much information about the vertical structure of the atmosphere, and it is now known that it is zoned or layered in various ways in terms of temperature change, chemical composition and electro-magnetic properties; a formidable jargon of -spheres has been coined.

It has been known for a long time that the temperature of the lower atmosphere falls at an average rate of 0-6°C per 100 m (3-3°F per 1000 ft) of ascent; this is termed the *environmental* (or static) *lapse-rate*. It is now realized that this decrease of temperature is limited to a certain height, which seems to be about 16 km (10 miles) at the Equator, 11 km (7 miles) at latitude 50°, and probably 9 km (5.5 miles) at the Poles, although these figures vary with the season (the point of change seems to be higher in summer) and with general atmospheric conditions. The lower atmosphere can be divided into two parts—the troposphere up to this level of change, the stratosphere up to about 50 km (30 miles); the discontinuity plane between them is known as the tropopause. At the latter, temperatures over the Equator vary during the year only from about –79°C (– 110°F) to –90°C (–130°F), though over the polar regions the seasonal difference is more marked, from about –40°C (–40°F) in summer to –79°C (–110°F) in winter.

Until recently the stratosphere was regarded as extending upwards to about 80-90 km (50-55 miles). It was known that from the tropopause to about 30 km (18 miles) temperatures rose very slightly. But still higher a change was found to occur; temperatures rose steeply to about 77°C (170°F) at 50 km (30 miles) and then fell equally steeply to about –100°C (–150° F) at 80 km (50 miles). This zone, therefore, from 50 km (a level known as the stratopause) to 80 km (the mesopause), which was formerly regarded as the upper stratosphere, is now called the *mesophere*. Within the stratosphere with a maximum at 25 km) is a zone of ozone concentration, which causes the absorption of the shorter ultra-violet rays from the sun's radiant energy, with the resultant heating of the thin atmosphere and the formation of this 'hot layer'. The longer ultra-violet rays, however, can pass through the ozonosphere to the earth's surface, producing the bronzing or 'sun-tan' which so many people desire.

Near the mesopause is the region of the silvery white noctilucent clouds, clearly visible in high latitudes during summer nights. It is not known whether these clouds are of water-vapour, ice-particles, or volcanic or ice-coated meteoritic dust; when a giant meteorite fell in Siberia in 1908, an unusually brilliant display of these clouds was seen the same evening, which seems to confirm that they are of dust.

Above the mesopause extends a zone known as the thermosphere, where temperatures would reach enormous levels, but since the density of the air is so small as to be a near-vacuum, very little heat can be absorbed, held or conducted.

The thermosphere broadly corresponds with the ionosphere, the zone in which electro-magnetic waves, including radio signals, are reflected back to earth. In this zone the atmospheric gases are ionized by incoming solar radiation. Above this again is the magnetosphere, the existence of which was postulated after two satellites, *Explorer I* and *II*, sent back to earth evidence of two zones of intense radiation, known as the Van Alien belts, the outer extending to about 16,000 km (10,000 miles) from the earth.

In these upper zones can be observed the Aurorae Boreah's and Australis in their respective hemispheres; though best developed at about 100 km (60 miles) altitude, they have ben recorded as far as 1000 km (600 miles). Their luminous effects are visible in high latitudes as red, green and white arcs, draperies, streamers, rays and sheets in the night sky. Probably this effect is the result of magnetic storms and of electrical discharges from the sun during periods of sun-spot activity or 'flares', mainly of electron particles funnelled into the earth's magnetic field and accelerated to the high energies necessary, thus causing ionization of gases. This seems to be con- firmed by recent American experiments, when an artificial aurora was produced by a rocket-borne device which fired bursts of electrons into the atmosphere. Results of the aurora include changes in the earth's magnetic field and black-outs in radio communication.

Constituents of the Atmosphere

Air is a mixture of gases, consisting mainly of about 78 per cent nitrogen and 21 per cent oxygen. Small quantities of carbon dioxide, hydrogen, and argon and other inert gases make up the remaining 1 per cent. These gases play a vital part in the radiation balance of the earth-atmosphere system.

In addition, air contains a variable quantity of water-vapour which plays a major role in the various weather phenomena. There is also much dust, specks of carbon in the form of soot, the spores of plants, salt particles evaporated from spray blown from the surface of the ocean, and minute pieces of disintegrating meteors, known as cosmic dust. One function of these particles is to serve as nuclei for the condensation of water-vapour.

It is now known as the result of space research that the constant chemical composition of the atmosphere refers only to that portion extending to a height of about 80 to 90 km (50 to 55 miles), to which has been given the name homosphere, extending broadly to the top of the mesosphere. Above the homosphere is the heterosphere, which consists of a series of concentric layers, in turn of molecular nitrogen, oxygen, helium and hydrogen. Though, interesting, the heterosphere obviously has little significance for the meteorologist.

TUNDRA CLIMATE

Location

Tundra is a Finnish word which means barren land. Thus, the tundra region having least vegetation and polar or arctic climate is found in North America and Eurasia between the southern limit of the permanent ice caps in the north and the northern limit of the taiga or subarcitc climate in the south. Thus, tundra climate has developed over parts of Alaska (USA), extreme northern parts of Canada, the coastal strips of Greenland and the arctic seasboard regions of European Russia and northern Siberia. Besides, tundra climate has also developed over arctic islands (Fig. 8.8). Vegetations rapidly change to the north of treeline because of increasing severity of climate.

Tundra climate is further divided into two subtypes *e.g.*, (i) *arctic tundra climate* and (ii) *alpine tundra climate* (which is found over high mountains of tropical to temperate areas). Based on variations in general vegetation characteristics arctic tundra is divided in 3 zones from south to north viz. (i) low arctic tundra, (ii) middle arctic tundra, and (iii) high arctic tundra. It may be pointed out that high, middle, and low are not indicative of altitudes rather these indicate latitudes.

The poleward boundary of tundra climate is demarcated by 0°C isotherm of the wannest month of the year while 10°C isotherm of the warmest month makes the equatorward boundary.

The tundra climate is characterized by general absence of insolation and sunlight and very low temperature throughout the year. The average annual temperature is –12°C. Winters are long, bitterly cold and very severe while summers are very short but cool. The warmest month of the year records average temperature between 0°C and 10°C. It is interesting to note that diurnal range of temperature is very low because of very little difference in day and night temperatures but the annual range is quite large. The severe climate does not favour much vegetation growth and hence most of the areas under tundra climate remain barren land. The ground surface is covered with snow at least for 7 to 8 months each year. The region is swept by speedy cold powdery storms known as blizzards. Growing season is less than 50 days in a year. The ground is permanently frozen (permafrost). Even soil is also perennially frozen.

Precipitation

Mean annual precipitation, mostly in the form of snowfall, is below 40 cm. The absolute humidity is very low because of very low rate of evaporation due to very low temperature throughout the year. The divergent system of air circulation and anticyclonic conditions do not favour much precipitation. Most of the annual precipitation is received during summer and autumn because of relatively higher temperature.

Natural Vegetation

There is prefect relationship between vegetation and the condition of moisture in the soils. The characteristic lithosols of tundra biome support only lichens and mosses. Only 3 per cent species of the total world species of plant could develop in tundra climate because of the severity of cold and the absence of minimum amount of insolation and sunlight. The vegetations of tundra climate are cryophytes *i.e.,* such vegetations are well adapted to severe cold conditions as they have developed such unique features which enable them to withstand extreme cold conditions. Most of the plants are tufted in form and range in height between 5 cm and 8 cm. These plants have the tendency of sticking to the ground surface because the temperature of the ground surface is relatively higher than the temperature of the overlying air. The herbs have developed only in those areas where heaps of ice and snow protect the plants from gusty icy winds. Such herbaceous plants include willow the stems of which are very close to the ground surface (hardly a few centimetres above the ground). Though the growth rate of these herbaceous plants is exceedingly slow but their survival period is unbelievably very long (between 150 to 300 years). The evergreen flowering plants develop on the ground like cushions mostly during short cool summers.

HEAT BUDGET

Definition : The earth receives heat energy from three basic sources viz. :

(i) Solar radiation,

(ii) Gravity, and

(iii) Endogenetic forces coming from within the earth but the solar radiation is the most significant source of terrestrial heat energy.

"The radiant energy received from the sun, transmitted in a form analogous to shortwaves (1/250 to l/6700mm in length), and travelling at the rate of 1,86,000 miles a second, is called solar radiation or insolation' (G.T. Trewartha). The sun is a great engine that drives winds on the earth's surface, ocean currents, exogenetic or denudational processes and ultimately sustains life in the biosphere. Solar energy received from the sun through solar radiation heats the earth's surface and the atmosphere and thus is responsible for the movement of air and currents through changes in pressure gradients, drives the hydrological cycle through evaporation and precipitation which in turn helps in the cycling and recycling of nutrients and chemical elements in the biosphere through the broader cyclic pathways collectively known as 'geobiochemical cycles', helps the plants to prepare their food through the process of photosynthesis' which infact, changes solar energy into chemical energy which is used by plants, animals and man, through different trophic levels of food chains and food webs.

MECHANISM OF SOLAR RADIATION

The source of energy of the sun is its interior wherein the hydrogen is converted into helium due to enormous confining pressure and very high temperature under the process of nuclear fusion which generates huge quantity of heat. This heat is transported to the outer surface of the sun through convection and conduction from below. It may be pointed out that the rate of generation of heat inside the sun is more or less constant and hence the radiation of energy from the outer surface of the sun (called as *photosphere*) is also more or less constant. Thus, the amount of solar radiation or the solar energy received on a unit area of the surface facing the sun at the average distance between the sun and the earth is also more or less constant and is called as solar constant. Thus, it is obvious that the solar constant refers to the rate of radiation from the sun which is of the value of 2 gram calories per square centimetre per minute (2 cal/cm^{2}min). It is also expressed in terms of langley (a unit measure of heat energy, one gram calorie per square centimetre is equal to one langley) as 2 langley per minute (2ly/min).

There are two basic laws which govern the nature and flow of radiation as given below :

(1) *Wien's displacement law* 'states that the wavelength of the radiation is inversely proportional to the absolute temperture of the emitting body.'

(2) *Stefan-Boltzmann law* states 'that flow, or influx, of radiation is proportional to the fourth power of the absolute temperature of the radiating body.'

The surface temperature of the sun is 6000°C or 11000°F. The highly incandescent gas of the sun's surface being heated from below emits bundle of energy called 'photon' which is infact the particle of radiation which has the property of wavelength. Continuous emission of photons from the sun's surface causes continuous bands of radiation having certain wavelength which is considered as short wavelength in relation to the earth's outgoing longwave radiation. The solar energy radiated from the outer surface of the sun in the form of electromagnetic wave is called as *electromagnetic radiation*, which travels at the speed of 3,00,000 km per second (1,86,000 miles per second). The solar energy received at the earth's surface is called *insolation* or *solar radiation*.

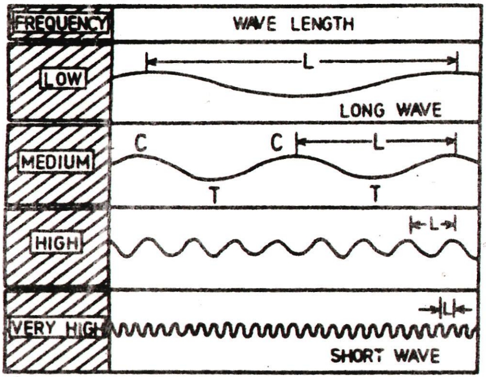

Fig. 2.4 : Relationship between wavelength and wave frequency, L = wavelength, C = wave crest, and T = wave trough.

The energy from the sun is emitted in the form of electromagnetic waves which travel outward in radial manner from the sun almost in straight line and take 8 minutes 20 seconds to reach the earth's surface after covering an average distance of 150 million km (93 million miles) between the sun and the earth. The electromagnetic radiation waves are expressed in terms of wavelengths (L). The straight distance between two successive crests or troughs is called wavelength (Fig. 2.4) (L) which is expressed in the length units of metres, centimetres, millimeters, microns etc.

The number of radiation waves (one radiation wave is equal to one wavelength) passing through a certain point per unit time (usually one second) is called *wave frequency* which varies according to the wavelengths of the radiation waves. There is inverse relationship between the wavelength and wave frequency *i.e.* shorter the wavelength, higher the wave frequency and longer the wavelength, lower the wave frequency (Fig. 2.4). In other words, high wave frequency is associated with short wavelength and low wave frequency is associated with long wavelength. Wave frequency is generally expressed as wave cycles per second. The wave cycles are usually expressed by the unit of measure of hertz. For example, one hertz per second represents one wave cycle meaning thereby only one wavelength passes per second from a fixed point. Hertz is further expressed in kilohertz (1,000 hertz) or megahertz (1,000,000 hertz).

Table 2.1: Amount of insolation received at the earth's surface from equator towards the poles (in percentage).

Latitudes	0	10	20	30	40	50	60	70	80	90
Insolation in per cent	100	99	95	88	79	68	57	47	43	42

Table 2.1 reveals the fact that the total amount of insolation received at the earth's surface decreases from equator towards the poles. The insolation becomes so low at the poles that they receive about 40 per cent of the amount received at the equator. The tropical zone extending between the tropics of Cancer (23.5°N) and Capricorn (23.5°S) receives maximum insolation. Not only this, there is very little variation of insolation during winter and summer seasons because every place experiences overhead sun twice every year. The globe is divided into 3 zones on the basis of the amount of insolation received during the course of a year.

(1) *Low latitude* or *tropical zone* extends between the tropics of Cancer and Capricorn. All places experience overhead sun (sun's rays are vertical) twice during the course of a year due to northward and southward march of the sun. Consequently, every place receives maximum and minimum insolation twice a year. The region receives highest amount of insolation of all other zones and there is little seasonal variation.

(2) *Middle latitude zone* extends between 23.5° and 66° latitudes in both the hemispheres. Within this zone every place receives maximum (at the time of summer solstice—21 June in the northern hemisphere and at the time of winter solstice—22 December in the southern hemisphere) and minimum (at the time of vernal

equinox—21 March in the northern hemisphere and at the time of autumnal equinox—23 September in the southern hemisphere) insolation once during the course of a year. Insolation is never absent at any time of the year but seasonal variation increases with increasing latitudes.

(3) *Polar zone* extends between 66° and 90° (poles) latitudes in both the hemispheres. Every place receives maximum and minimum insolation once during the course of a year but some times insolation becomes zero due to absence of direct solar rays.

FACTORS AFFECTING THE DISTRIBUTION OF INSOLATION

It is apparent from the foregoing discussion that the amount of insolation received at the earth's surface varies significantly (decreases) from equator towards the poles due to certain astronomical and geographical factors viz. :

(i) Angle of the sun's rays,

(ii) Length of day,

(iii) Distance between the sun and the earth,

(iv) Sunspots, and

(v) Effects of the atmosphere.

Angle of the Sun's Rays

The angle between the rays of the sun and the tangent to the surface of the earth at a given place largely determines the amount of insolation to be received at that place. The sun's rays are more or less vertical (maximum angle of 90° between the sun's rays and the tangent to the earth's surface) at the equator and become more and more oblique poleward. In other words, the angle of the sun's rays decreases poleward. As per rule vertical rays bring more insolation than oblique rays. In other words, as the angle of sun's rays decreases poleward, the amount of insolation received also decreases in that direction. The control of the angle of the sun's rays on the amount of insolation may be explained with the following examples :

(i) Vertical rays are spread over minimum area of the earth's surface and they heat the minimum possible area and thus the energy received per unit area increases. On the other hand, oblique rays are spread over larger area of the earth's surface and hence the amount of energy received per unit area decreases. It is, obvious from Fig. 2.5 that A and B bands of the sun's rays are of reinforce width and carry equal amount of solar energy but the area (S) covered by A band is much smaller than the area covered by B band (O) and therefore the amount of insolation received per unit area over S surface is greater than over O surface area (Fig. 2.5)

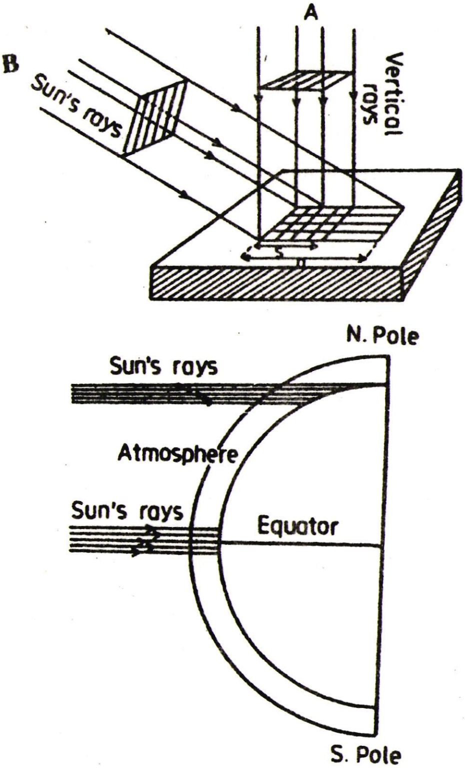
A
B
Sun's rays
Vertical rays
S
O
N. Pole
Sun's rays
Atmosphere
Sun's rays
Equator
S. Pole

Fig. 2.5 : Effect of the angles of sun's rays on the distribution of insolation.

(ii) Oblique rays have to pass through thicker portion of the atmosphere than the vertical rays. Thus, the oblique rays have to traverse larger distances than the vertical rays. Consequently, the amount of solar energy lost due to reflection, scattering and absorption increases with increasing distance of travel path covered by the sun's rays through the atmosphere (Fig. 2.5). It may be summarized that the oblique rays lose more energy than the vertical rays while passing through the atmosphere.

Length of Day

If all the other conditions are favourable and equal then longer duration of sunshine (or length of day) and shorter duration of night enable the ground surface to receive larger amount of insolation. On the other hand, shorter the duration of sunshine and longer the period of night, the lesser the amount of insolation received at the earth's surface. The length of day varies at all places except at the equator due to inclination of the earth's axis, its parallelism and the earth's rotation and revolution. The length of day is always of 12 hours at the equator because the circle of illumination or light circle always divides the equator into two equal halves. But the length of day increases poleward with northward march of the sun in the northern hemisphere while it decreases in the southern hemisphere at the time of summer solstice (21 June). On the other hand, the length of day increases from the equator poleward in the southern hemisphere but it decreases in the northern hemisphere at the time of winter solstice (22 December) (southward march of the sun). It is important to note that the duration of day becomes of 6 months at the north pole from 21 March to 23 September during the northward migration of the sun while the night is of the duration of 6 months at the south pole during this period. Conversely, the length of day becomes of 6 months at the south pole (23 September to 21 March) during the southward migration of the sun while the night becomes of 6 months at the north pole during this period. Inspite of increasing length of day from the equator towards the north pole during summer solstice and from the equator to the south pole during winter solstice amount of insolation received at the ground surface decreases considerably poleward because of decrease in the angle of sun's rays. Inspite of the longest length of day at the poles insolation becomes minimum. because :

(i) the sun's rays become more or less parallel to the ground surface, and

(ii) the ice cover reflects most of the solar radiation. It is apparent that the angle of the sun's rays controls the amount of insolation received more effectively than the length of day. It may be, thus, concluded that the places having longer length of day and vertical sun's rays will certainly receive maximum insolation.

Table 2.2: Maximum length of day at different latitudes

Latitude	0	17	31	41	49	58.5	63.4	66.5	67.4	69.8	78.2	90
Length of day (hours)	12	13	14	15	16	18	20	24	1 month	2 months	4 month	6 months

Distance between the Earth and the Sun

The distance between the sun and the earth changes during course of a year because the earth revolves around the sun in elliptical orbit. The average distance between the sun and the earth is about 93 million miles (149 million kilometres). At the time of perihelion on January 3 the earth is nearest to the sun, say 91.5 million miles (147 million kilometres) away while at the time of aphelion on July 4 it is farthest from the sun, say 94.5 miles (152 million kilometres) away (Fig. 2.6). As per rule, the earth at the time of perihelion, when it is nearest to the sun, should receive maximum insolation while it should receive minimum insolation at the time of aphelion when the earth is at the greatest distance from the sun. In fact, in the month of January, when the earth is nearest to the sun, there is winter season instead of summer season in the northern hemispheres due to low amount of insolation received. On the other hand, in the month of July, when the earth is farthest from the sun, there is summer instead of winter in the northern hemisphere due to high amount of insolation received. It is obvious that factors of the angle of the sun's rays and length of day play more dominant role in the distribution of insolation than the factor of varying distances between the earth and the sun. Of course winters are 7 per cent less severe in January in the northern hemisphere but summer is 7 per cent more intense in the southern hemisphere at the time of perihelion while summer is 7 percent less intense in July in the northern hemisphere but winter is 7 per cent more intense in the southern hemisphere at the time of aphelion.

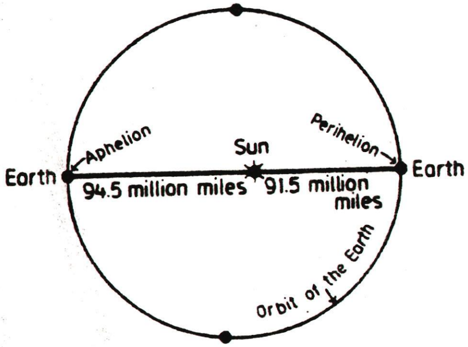

Fig. 2.6 : Relative distance between the sun and the earth.

Sunspots

Sunspots are created in the solar outer surface due to periodic disturbances and explosions. The number of sunspots varies from year to year. The studies have shown that the variation in the number of sunspots is cyclic in nature. In other words, the increase and decrease of number of sunspots is completed in a cycle of 11 years. During every 11th year there is maximum number of sunspots. The energy radiated from the sun increases when the number of sunspots increases and therefore the amount of insolation received at the earth's surface also increases. On the other hand, the amount of insolation received at the earth's surface decreases when the number of sunspots decreases.

Effects of the Atmosphere

The electromagnetic solar radiation or the incoming shortwave solar radiation has to pass through thick layer of the earth's atmosphere and hence it is partly absorbed, partly reflected and partly scattered by the atmosphere and partly transmitted to the earth's surface.

Absorption

If the total amount of energy radiated from the sun towards the earth and its atmosphere (which is 1.2 billionth part of the total energy radiated from the photosphere of the sun) is taken to be 100 per cent, about 14 per cent of this amount is absorbed by the atmospheric gases (*e.g.*, by ozone in the stratosphere to larger extent and oxygen and carbon dioxide to very limited extent), water vapour, haze etc. The process of absorption is selective in nature. The shortest wavelengths ranging between 0.02 micron and 0.29 micron are absorbed by oxygen (O_2) and ozone (O_3) gases.

Ozone also absorbs ultraviolet rays of the wavelengths varying from 1000 angstroms to 4000 angstroms and thus prevents these ultraviolet radiation waves from reaching the earth's surface. Water vapour absorbs the incoming solar radiation waves of the wavelengths ranging between 0.9 micron and 2.1 microns.

Scattering

Some portion of the incoming electromagnetic solar radiation (23%) is scattered in the atmosphere by dust particles and haze. Six per cent of this scattered energy is sent back to space while 17 per cent reaches the earth's surface. The process of scattering is selective in nature. Scattering becomes possible when the diameter of invisible dust particles suspended in the air and the molecules of the atmospheric gases is shorter than the wave lengths of the solar radiation waves.

Blue light of the incoming shorter wavelengths is more scattered than red light. This is the reason that the sky Similarly, the picturesque reddish hue of the sky during sunrise (dawn) and sunset (twilight) is the result of scattering of all the colour spectra except the red and orange because at the time of sunrise and sunset the oblique rays have to pass through the longest path of the atmosphere.

Reflection

The scattering of incoming solar radiation waves by dust particles and molecules of water vapour (clouds) when the diameter of these particles is longer than the wavelengths of incoming solar radiation is called *diffuse reflection* which sends some portion of incoming solar energy back to space while some portion remains in the lower atmosphere. The diffused and scattered solar energy present in the lower atmosphere enables us to see even the dark portion of the moon. One can also see (if not suffering from cataract) even in the pitch darkness of night. Some of the scattered and diffused solar energy reaches the ground surface. Such energy is called as *diffuse blue light* of the sky or diffuse day light. Some portion of incoming solar radiation is reflected back to space by high clouds (27 per cent) and by the ice-covered ground surface (2 per cent).

The portion of incident radiation energy reflected back from a surface is called *albedo*. Various attempts have been made to measure total albedo of the earth (including its atmosphere). Various data derived so far indicate the earth's average albedo fluctuating between 29 per cent and 34 per cent (including the energy reflected through the mechanism of diffuse reflection by dust particles, water molecules etc., (from the cloud surface and from the earth's surface). The albedo of other planets has also been estimated *e.g.*, Moon (7%), Mercury (6%), Mars (16%), Venus (76%) and the remaining outer planets (73% to 94%).

It may be pointed out that the processes of absorption, scattering and reflection are not as simple as discussed above rather they are highly complex. Further more, the figures used here to indicate the quantity of solar radiation lost during its passage through the atmosphere by different processes are mere estimates and these vary from the estimates of one scientist to the other.

HEAT BUDGET OF THE EARTH AND THE ATMOSPHERE

'The total solar radiation reaching a horizontal surface on the ground is called global radiation. It comprises the direct shortwave radiation from the sun, plus the diffuse radiation scattered by the atmosphere' (J.E. Hobbs, 1980). On an average, there is supposed to exist heat balance between the amount of solar radiation received by the earth's surface and its atmosphere and the amount of heat lost by the outgoing terrestrial longwave radiation from the earth's surface and loss of heat from the atmosphere. It may be pointed out that the solar energy received at the earth's surface is convened into heat energy which heats the outer surface of the earth. Thus, the earth after being heated also radiates energy in the form of longwave radiation. The radiation from the sun towards the earth and from the earth towards the atmosphere and the space is called *incoming shortwave solar radiation* (radiation from the sun) and *outgoing longwave terrestrial radiation* (from the earth) respectively.

The estimated data of G.T. Trewarha are being used to explain the heat budget of the earth and its atmosphere.

Incoming Shortwave Solar Radiation and the Heat Budget of the earth and the Atmosphere

The earth receives most of its energy from the sun through shortwave solar radiation. The solar energy radiated towards the earth's surface (1/2 billionth part of the total energy radiated from the outer surface-*photosphere* of the sun which is equivalent to 23 trillion horse power) is taken as 100 per cent or 100 units. Out of the total incoming solar radiation entering the earth's atmosphere 35 per cent is sent back to space through scattering by dust particles (6%), reflection from the clouds (27%) and from the ground surface (2%), 51 per cent is received by the earth's surface (received as direct radiation), and 14 per cent is absorbed by the atmospheric gases (ozone, oxygen etc.) and water vapour in different vertical zones of the atmosphere. The 51 per cent solar energy received by the earth comprises 34 per cent as direct solar radiation and 17 per cent as *diffuse day light.*

Outgoing Longwave Terrestrial Radiation and Heat Balance

After receiving energy from the sun the earth also radiates energy out of its surface into the atmosphere through longwaves.

The terrestrial radiation is also called 'effective radiation' because it helps in heating the lower portion of the atmosphere. Twenty three per cent energy (out of 51% energy which the earth has gained from the sun) is lost through direct longwave outgoing terrestrial radiation out of which 6 per cent is absorbed by the atmosphere and 17 per cent goes directly to the space. About 9 per cent of the terrestrial energy is spent in convection and turbulence and 19 per cent is spent through evaporation which is added to the atmosphere as latent heat of condensation.

NET RADIATION AND LATITUDINAL HEAT BALANCE

The difference between all incoming solar energy and all outgoing terrestrial energy by both shortwave and longwave radiation is called net radiation. It is apparent from the aforesaid discussion that the net radiation from the whole globe is at least theoretically zero but this is far from truth if we look at the regional distribution of insolation. There are some places where the receipt of solar energy is more than the energy lost because the solar energy comes at faster rate than the terrestrial energy goes out. Similarly, in some areas the loss of energy through outgoing terrestrial radiation is faster than the gain of incoming solar radiation. This mechanism results in the development of areas of energy surplus (where incoming solar radiation exceeds outgoing terrestrial radiation and energy deficit (where outgoing terrestrial radiation exceeds incoming solar radiation).

Table: 2.3 : Annual Meridional Heat Transport

Latitudes (northern hemisphere)	*Heat transport (kilo calories per year × 10^9)*	*Latitudes (northern hemisphere*	*Heat transport (kilocalories per year × 10^9)*
90	0.00	40	3.91
80	0.35	30	3.56
70	1.25	20	
60	2.40	10	2.54
50	3.40	09 (equator)	–0.26

Source: W.D. Sellers, 1965.

The energy surplus and energy deficit areas may be identified and studied at two levels viz. :

(i) *At the earth's surface,* and

(ii) *In the atmosphere,* latitudinal base being common in both the cases,

(iii) The distribution of net radiation at the earth's surface from equator towards the poles shows that :

   (a) there is large *energy surplus area* between the zones of 20°N and 20°S where energy gain from the incoming solar radiation is more than the loss of energy through outgoing longwave terrestrial radiation and the annual surplus energy amounts to 100 kilolangleys per year;

   (b) net radiation rapidly decreases from the energy surplus areas of low latitudes towards mid-latitudes;

   (c) net radiation becomes practically zero near 70° latitude in the northern and southern hemispheres, and

   (d) the polar areas are the zones of perennial energy deficit

The latitudinal distribution of net radiation in the atmosphere shows that 'the atmosphere is itself a net loser of radiation at all latitudes' (J.E. Hobbs, 1980). Thus, the atmosphere is the zone of perennial energy deficit because the deficit of energy always exceeds 60 kilolangleys per year.

If the data of net radiation of both, the earth's surface and the atmosphere, are combined together, the net radiation value for the combined '*earth's surface-atmosphere system*' may be calculated. Based on the combined data the following energy zones are identified :

(a) Large region of surplus radiation extending between 40°N and 30°S latitudes.

(b) Northern high-latitudes of deficit radiation, and

(c) Southern high-latitudes of deficit radiation (A.N. Strahler, 1978).

It means that "there must exist a two-way heat transfer; from the earth's surface to the atmosphere and from the equator to the poles" (J.E. Hobbs, 1980). This can be achieved if heat is transported from the earth's surface to the atmosphere and from the tropical and subtropical areas of surplus radiation to the high latitude zones of deficit radiation. The transport of heat from equatorial area towards the poles is called '*meridional transport of heat*'.

The meridional transport of heat energy in the form of *sensible heat* is accomplished by the atmospheric circulation and ocean currents which transport heat energy from the 'low latitude surplus energy areas' to the 'high latitude deficit energy areas.' The vertical transport of heat in the atmosphere is accomplished by ascending air in the form of sensible heat and latent heat.

3

ATMOSPHERE STRUCTURE

INTRODUCTION

The modern knowledge about the atmosphere is based on the information received through rockets, radar and satellites. The effective height of the atmosphere is estimated between 16 and 29 thousand kilometres from the sea level but the height of the atmosphere upto 800 km is most important.

About 50 per cent of the atmosphere lies below the altitude of 5.6 km and 97 percent of the atmosphere is confined to the height of only 29 km. The upper limit of the atmosphere, though unknown, is considered to be 10,000 km from sea level. The earth's atmosphere consists of a few zones or layers like spherical shells. On the basis of the characteristics of temperature and air pressure there are four layers from the earth's surface upward *e.g.* :

(1) Troposphere,

(2) Stratosphere,

(3) Mesosphere, and

(4) Thermosphere..

(1) Troposphere

The lower most layer of the atmosphere is known as troposphere and is the most important layer because almost all of the weather phenomena (*e.g.*, fog, cloud, dew, frost, rainfall, hailstorm, storms, cloud-thunder, lightning etc.) occur in this layer. Thus, the troposphere is of utmost significance for all the life forms including man in the biospheric ecosystem because these are concentrated in the lowest part of the atmosphere. Temperature decreases with increasing height at the rate of 6.5°C per 1000m. This rate of decrease of temperature is called normal lapse rate. There is seasonal variation in the height of troposphere. In other words, the height of troposphere changes from equator towards the poles (decreases) and from one season of a year to other season (increases during summer while it decreases during winter). The average height of the troposphere is about 16 km over the equator and 6 km over the poles. The upper limit of the troposphere is called *tropopause* which is about 1.5 km thick. The height of tropopause is 17 km over the equator and 9 to 10 km over the poles. There is also seasonal variation in the height of tropopause. Its height is 17 km during January and July over the equator and the temperature at this height is –70°C. The height of tropopause during July and January over 45°N latitude is 15 km (temperature –60°C) and 12.5 km (temperature –58°C) respectively. The height decreases further poleward as it is 10 km during July (temperature –45°C) and 9 km during January (temperature –58°) over the north pole. It is apparent that temperature at the top of tropopause is lowest over the equator (–70°C) and is relatively high over the poles. Since temperature decreases upward at the rate of 6.5°C per 1000m and hence it is natural that temperature at the height of 17 km over the equator becomes much lower than at the height of 9-10 km over the poles. The word troposphere literally means 'zone or region of mixing' whereas the word tropopause means 'where the mixing stops'.

(2) Stratosphere

The layer just above the troposphere is called *stratosphere* but there is contrasting opinion about the height and thickness of this layer. The average height over the middle latitudes has been determined to be 25-30 km, whereas it is estimated to be 80 km by others. On an average the upper limit of the stratosphere is taken to be 50 km. There is also contrasting opinion about the change or no change of temperature with increasing height in this sphere. A few scientists believe that the stratosphere is isothermal *i.e.,* there is no change in temperature with increasing height while others hold that temperature gradually rises upward as it becomes 0°C or 32°F at the height of 50 km, the upper limit of the stratosphere which is known as *stratopause*.

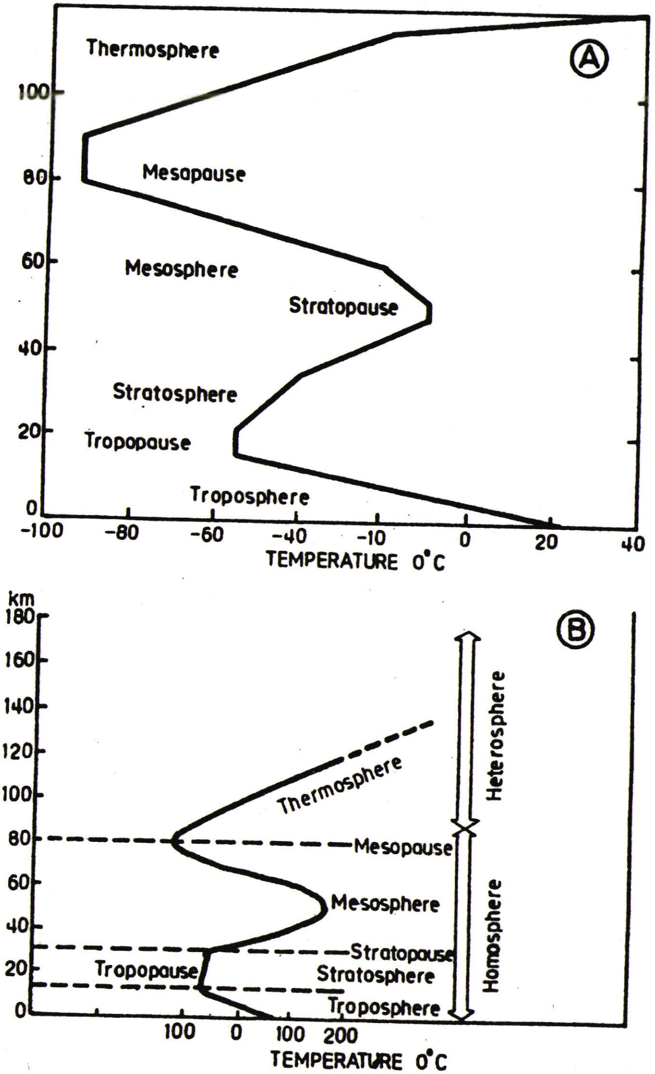

Fig. 3.1 : Stratification of the atmosphere. (A) According to Bary and Charley. (B) According to A.N. Strahler.

Though, the stratosphere is more or less devoid of major weather phenomena but there is circulation of feable winds and cirrus cloud in the lower stratosphere. The lower part of this layer is very important for life-forms in the biospheric ecosystem because there is concentration of ozone between the height of 15-30 km though ozone has been discovered upto the height of 80km.

The lower portion of the stratosphere having maximum concentration of ozone is called ozonosphere, which is confined between the height of 15 km to 35 km from sea level though the upper limit has been fixed at 55 km. Ozone (O_3) defined as 'a three-atom isotope of oxygen or merely a triatomic form of oxygen (O_3) is a faintly blue irritating gas with a characteristic pungent odour. The ozone gas is unstable because the creation and destruction of this gas is a gradual and continuous natural process.

It acts as a protective cover for the biological communities in the biosphere because it absorbs almost all of the ultra-violet rays of solar radiation and thus protects the earth's surface from becoming too hot. Recently, the researches have shown that there is gradual depletion of ozone gas in the atmosphere due to human activities. It may be pointed out that combining of atmospheric oxygen (O_2) with individual oxygen molecules results in the creation of ozone ($O_2 + O \rightarrow O_3$) whereas the breaking of ozone (O_3) into O_2 and O results in the depletion or destruction of ozone. The main culprits of ozone destruction are halogenated gases called chlorofluorocarbons, halons and nitrogen oxides. The chlorofluorocarbons, popularly known as CFCs, belong to the category of synthetic chemicals and are relatively simple compounds of the elements chlorine, fluorine and carbon and are initially stable compounds which do not have any toxic effect on life processes in the biosphere at ground level. These synthetic chemicals are widely used as propellants in spray can dispensers, as fluids in air conditioners and refrigerators etc. Chlorofluorocarbons, when used as propellants, are released into the air and are transported in the stratosphere by vertical atmospheric circulation. Chlorine when separated from chlorofluorocarbons reacts with water and thus depletes ozone rather breaks ozone into O_2 and O. Besides, nitrogen oxides released by supersonic jets which fly at the height of 18-22 km also depletes ozone. Depletion of ozone would result in the rise of temperature of the ground surface and lower atmosphere. This would cause global warming, acid rain, melting of continental glaciers and rise in sea level, skin cancer to white-skinned people, poisonous smogs, decrease in photosynthesis, ecological disaster and ecosystem instability.

(3) Mesosphere

Mesosphere extends between 50 km and 80 km. Temperature again decreases with increasing height. In fact, the rise of temperature with increasing height in the stratosphere stops at stratopause. At the uppermost limit of mesosphere (80 km) temperature becomes –80°C. This limit is called *mesopause* above which temperature increases with increasing height.

(4) Thermosphere

The part of the atmosphere beyond mesopause is known as thermosphere wherein temperature increases rapidly with increasing height. It is estimated that the temperature at its upper limit (height undecided) becomes 1700°C. It may be pointed out that this temperature cannot be measured by ordinary thermometer because the gases become very light due to extremely low density. That is why one does not feel warm when one stretches one's arm in the air. Thermosphere is divided into two layers viz.:

(i) Ionosphere, and

(ii) Exosphere.

(1) *Ionosphere* extends from 80 km to 640 km. There are a number of ionic layers (with increasing heights) in this sphere *e.g.*, D layer, E layer, F layer, and G layer. *D layer* (between the height of 60 km–99 km) reflects the signals of low frequency radio waves but absorbs the signals of medium and high frequency waves. This layer disappears with the sunset because it is associated with solar radiation. E layer, also known as *Kennelly—Heaviside layer*, is confined in the height between 99 km–130 km. This layer reflects the medium and high

frequency radio waves back to the earth. This layer is produced due to interaction of solar ultra-violet photons with nitrogen and nitrogen molecules and thus, it also disappears with the sunset. *Sporadic E layer* is associated with high velocity winds and is created under special circumstances. This layer reflects very high frequency radio waves. *E_2 layer* is generally found at the height of 150 km and is produced due to reaction of ultra-violet solar photons with oxygen molecules and thus this layer also disappears during nights. F layer consists of two sub-layers *e.g.*, F_1 and F_2 layers (150 km – 380 km) and are collectively called 'appleton layer'. These layers reflect medium and high frequency radio waves back to the earth. G layer (400 km and above) most probably persists day and night but is not detectable.

(2) *Exosphere* represents the uppermost layer of the atmosphere. In fact, we know very little about the atmosphere extending beyond 640 km height from the sea level. The density becomes extremely low and the atmosphere resembles a nebula because it is highly rarefied. The temperature becomes 5568°C at its outer limit but this temperature is entirely different from the air temperature of the earth's surface as it is never felt.

CHEMICAL COMPOSITION OF THE ATMOSPHERE

On the basis of chemical composition, the atmosphere is divided into two broad zones viz.:

(1) Homosphere,
(2) Heterosphere.

(1) *Homosphere* represents the lower portion of the atmosphere and extends upto the height of 90 km from sea level. The main constituent gases are oxygen (20.946%) and nitrogen (78.084%). Other gases are argan, carbon dioxide, neon, helium, krypton, xenon, hydrogen etc.

This zone is called *homosphere* because of the homogeneity of the proportion of various gases. In other words, the proportions of different gases are uniform at different levels in this zone. It may be pointed out that man is increasingly disturbing the natural proportions of gases through his ever increasing economic activities and modem technologies. For example, the proportion of carbon dioxide is rapidly increasing due to burning of fossil fuels (coal, petroleum and natural gas) and deforestation. The concentration of atmospheric carbon dioxide at the beginning of the industrial revolution (1860 A.D.) was fixed at 280 to 290 ppm (parts per million) by volume but now it has increased to 350-360 ppm (1988 A.D.)

Thus, registering an overall increase by 25 per cent from the pre-industrial level. On the other hand, the proportion of ozone gas is rapidly decreasing due to ever increasing production and consumption of CFCs (chlorofluorocarbons) and halogenated gases. On the basis of thermal conditions the homosphere has been divided into three layers viz. :

(i) Troposphere,

(ii) Stratosphere, and

(iii) Mesosphere.

(2) *Heterosphere* extends from 90 km to 10,000 km. Different layers of this sphere vary in their chemical and physical properties. There are four distinct layers of gases in this sphere:

(i) Molecular nitrogen layer is dominated by molecular nitrogen and extends upward upto the height of 200 km (90 to 200 km),

(ii) Atomic oxygen layer extends from 200 to 1100 km.

(iii) Further, upward there is helium layer which extends upto the height of 3500km.

(iv) Atomic hydrogen layer is the topmost layer of the atmosphere and extends upto the outermost limit of the atmosphere.

ELEMENTS OF WEATHER AND CLIMATE

Weather refers to the sum total of the atmospheric conditions in terms of temperature, pressure, wind, moisture, cloudiness, precipitation and visibility of a particular place at any given time. In fact, weather denotes short-term variations of atmospheric conditions and it is highly variable. On the other hand, climate is defined as aggregate weather conditions of any region in long-term perspective. According to Trewartha 'climate represents a composite of day to day weather conditions, and of the atmospheric elements, within a specified area over a long period of time.'

According to Critchfield 'climate is more than a statistical average; it is the aggregate of atmospheric conditions involving heat, moisture, and air movement. Extremes must always be considered in any climatic description in addition to means, trends, and probabilities.' According to Koeppen and De Long 'climate is a summary, a composite of weather conditions over a long period of time; truly portrayed, it includes details of variations-extremes, frequencies, sequences of the weather elements which occur from year to year, particularly in temperature and precipitation. Climate is the aggregate of the weather.' G.F. Taylor has maintained that 'climate is the integration of weather, and weather is the differentiation of climate. The distinction between weather and climate is, therefore, mainly one of time.' Temperature, pressure, wind, humidity, precipitation, cloudiness etc. are elements of weather and climate.

CONTROLS OF WEATHER AND CLIMATE

There are frequent changes in weather conditions. These changes from one day to the other or from one place to the other are due to variations in the quantity, intensity and distribution of the elements of weather and climate. Similarly, there is variation in climatic conditions from one area to the other area. The factors controlling the variations of the elements of weather and climate from one place to the other place and from one season to the other season are called controls of weather and climate. These factors include latitudes, altitudes, unequal distribution of land and water, ocean currents, air pressure and wind, mountain barrier, nature of ground surface, different types of atmospheric storms etc.

TEMPERATURE

Here, temperature means atmospheric temperature. Indirectly the sun is the major source of atmospheric temperature. In fact, the atmosphere receives very low amount of heat energy from the sun as it receives most of its energy from the longwave terrestrial radiation. Atmosphere receives energy from the sun and the earth in different ways. On an average, the heating and cooling of the atmosphere is accomplished through direct solar radiation and through transfer of energy from the earth through the processes of conduction, convection and radiation. It may be pointed out that 'heat' and 'temperature' generally appear synonym to common people but these two terms differ considerably as regards their real meaning. Heat is a form of energy while temperature denotes the intensity of hotness or coldness of any substance. In other words, heat denotes the quantity of energy present in any substance while temperature refers to the degree of hotness of that subject. Thus, the temperature of any substance may be raised or lowered with the addition or substraction of heat. The transfer of heat from one body to the other is accomplished through conduction, convection, and radiation.

HEATING AND COOLING OF THE ATMOSPHERE

The solar energy received by the earth's surface including both ground surface and water surface (of the seas and the oceans) is convened into heat energy in the form of sensible heat (heat that can be measured by thermometer) and is temporarily stored. This stored energy is radiated from the ground and water surface in the form of longwaves into the atmosphere. The process of radiation of heat energy from the earth's surface is called ground radiation (including radiation from both, ground surface and water surface). The part of this ground radiation after being absorbed by the atmosphere is again radiated back to the earth's surface. This process of radiation of terrestrial heat energy from the atmosphere back to the earth's surface is called counter-radiation. The counter-radiation is effected mainly by water vapour and atmospheric carbon dioxide.

Heating of the Atmosphere by Direct Insolation

The heat energy is radiated from the outer surface of the sun (photosphere) in the form of longwaves. The atmosphere absorbs 14 per cent of incoming short wave solar radiation through ozone, water vapour etc. present therein. Seven per cent of this energy is spread in the lower atmosphere up to the height of 2km. It is apparent that this amount is too low to heat the atmosphere significantly.

Conduction

The transfer of heat through the molecules of matter in any body is called conduction. The transfer of heat under the process of conduction may be accomplished in two ways viz.:

(i) from one part of a body to the other part of the same body, and

(ii) from one body to the other touching body.

Conduction may be effective only when there is difference in temperatures in different parts of a single body or in two bodies and the process continues till the temperatures of all parts of a body or of two touching bodies become same. It is obvious that heat moves from warmer body to the cooler body through molecular movement. The rate of transfer of heat through molecular movement depends on the heat conductivity of the substance. The substance or a body which allows transfer of heat through conduction at a very fast rate is called good conductor of heat while the substance or a body which retards conduction of heat is called bad or poor conductor of heat. Metal is a good conductor of heat while air is very poor conductor of heat. The earth's surface is heated during day-time after receiving solar radiation. The air coming in contact with the warmer ground surface is also heated because of transfer of heat (conduction of heat) from the ground surface through the molecules to the air. Since air is very poor conductor of heat and hence the transfer of heat from the ground surface through conduction is effective only upto a few metres in the lower atmosphere. The ground surface becomes colder than the air above during winter nights and thus heat is transferred from the lower portion of the atmosphere to the ground surface and thus the atmosphere is cooled.

Terrestrial Radiation

The process of transfer of heat from one body to the other body without the aid of a material medium (*e.g.*, solid, liquid or gas) is called radiation. There are two basic laws which govern the nature of flow of heat energy through radiation.

(a) *Wien's displacement law* 'states that the wavelength of the radiation is inversely proportional to the absolute temperature of the emitting body'.

(b) *Stefan-Boltzmann law* 'states that flow, or flux of radiation is proportional to the fourth power of the absolute temperature of the radiating body'.

The earth's surface after receiving insolation from the sun through shortwave electromagnetic radiation gets heated and radiates heat to the atmosphere in the form of longwave or infrared radiation throughout 24 hours. It may be remembered that the atmosphere is more or less transparent for incoming shortwave solar radiation but it absorbs more than 90 per cent of outgoing longwave terrestrial radiation through water vapour, carbon dioxide, ozone etc. Thus, the terrestrial radiation is the most important source of heating of the atmosphere. The process of radiation of heat from the earth's surface is called *ground radiation*. The part of this ground radiation after being absorbed by the atmosphere is radiated back to the earth's surface. This process of radiation of terrestrial heat energy from the atmosphere back to me earth's surface is called *counter-radiation* which is effected mainly by water vapour and atmospheric carbon dioxide. This mechanism known as greenhouse effect keeps the lower atmosphere and the ground surface relatively warmer. Thus, the atmosphere acts as window glasspane which allows the shortwave solar radiation to come in and prevent the longwave terrestrial radiation to escape into space.

It is obvious that the increase in the concentration of carbon dioxide in the atmosphere will increase the greenhouse effect and thus the temperature of the earth's surface would increase. It may be pointed out that carbon dioxide also absorbs longwave terrestrial radiation and helps in keeping the lower atmosphere and the ground surface warmer. Water vapour absorbs both the incoming shortwave solar radiation and outgoing longwave terrestrial radiation. Since most of water vapour is concentrated in the lower atmosphere (90 per cent of the total atmospheric water vapour is found upto the height of 5km in the lower atmosphere) and hence both the incoming solar radiation and outgoing terrestrial radiation increase with increasing height. This is the reason that high mountains are called radiation windows.

Convection

The transfer of heat energy through the movement of a mass of substance from one place to another place is called convection. The process of convection becomes effective only in fluids or gases because their internal mass motion activates convection of heat energy. The earth's surface gets heated after receiving heat energy (insolation) from the sun. Consequently, the air coming in contact with the warmer earth's surface also gets heated and expands in volume. Thus, warmer air becomes lighter and rises upward and a vertical circulation of air is set in.

Conversely, the relatively colder air aloft becomes heavier because of contraction in volume and thus descends to reach the earth's surface. The descending air is wanned because of dry adiabatic rate and warm ground surface. This warm air again ascends because of increase in volume and decrease in density. The whole mechanism of ascent of warmer air and descent of colder air generates convection currents in the lower atmosphere. This convective mechanism transports heat from the ground surface to the atmosphere and thus helps in the heating of the lower atmosphere. Similarly, horizontal convection currents are also generated on the ground surface.

Besides, atmosphere is also heated through latent heat of condensation, and expansion and compression of air.

MEAN TEMPERATURES

All types of average temperatures *e.g.*, monthly, seasonal and annual means, depend on daily temperatures and their averages. The earth receives energy (insolation) through the electromagnetic shortwaves radiated from the photosphere (outer surface of the sun) of the sun during day time. This radiant energy is transformed into heat. The earth's surface receives maximum energy at 12 noon but the maximum temperature never occurs at 12 noon because the transformation of solar energy into heat requires time. The energy received by the earth from solar radiation continues to exceed the energy lost by outgoing longwave radiation from the earth's surface from 6 A.M. to 2-4 P.M. Thus, the curve of air temperature also rises upto 4 P.M. This is why maximum temperature is recorded between 2 P.M.- 4 P.M. The highest temperature recorded within 24 hours is called maximum daily temperature. On the other hand the loss of energy through longwave radiation from the earth's surface exceeds the energy received from the sun from 4 P.M. to the sunrise and hence there is gradual fall of the curve of temperature but the lowest (minimum) temperature is recorded between 4-5 A.M. instead of midnight. The lowest temperature within 24 hours is called *minimum daily temperature*. Thus, there is no coincidence between the time of maximum and minimum amount of insolation received from the sun and maximum and minimum temperatures of the air. This is called *lag of temperature*. The average of maximum and minimum temperatures within 24 hours is called *mean daily temperature*. Similarly, the mean of daily maximum and minimum temperatures of a month is called mean monthly maximum temperature and mean monthly minimum temperature. Mean of maximum and minimum temperatures of 12 months is called mean annual maximum and mean annual minimum temperature. The difference between the maximum and minimum temperatures of a day (24 hours) is called daily or diurnal range of temperature. Similarly, the differences between the monthly maximum and minimum temperatures on one hand and between annual maximum and minimum on the other hand are called monthly range and annual range of temperatures respectively.

DISTRIBUTION OF TEMPERATURE

The spatial and temporal distribution of temperatures is very significant because different types of weather, climates, vegetation zones, animals and human life etc. basically depend on the distribution of temperature, whether horizontal or vertical. The study of distribution of temperature is attempted in several ways viz.:

(i) Temporal distribution, and

(ii) Spatial distribution.

The spatial distribution is studied in two ways *e.g.,*:

(a) vertical distribution, and

(b) horizontal distribution of temperature.

The horizontal distribution of temperature is also termed as regional distribution of temperature. The-spatial distribution of temperature is controlled by a variety of factors *e.g.*, latitudes or distance from the equator, height from sea level or altitude, distance from the sea coast, nature of land and water, properties of ground surface, nature of slopes, prevailing winds, oceans currents etc.

Factors Controlling the Distribution of Temperature

As elaborated above the following factors control the distribution of temperature on the earth's surface :

Ocean Currents

The warm ocean currents flowing from tropical areas to temperate and cold zones raise the average temperature in the affected areas. For example, Gulf Stream raises the average temperature of the coastal areas of north-western Europe while Kuroshio warm current raises the temperature of Japanese coasts. Labrador, Peru, California, Kurile etc. cold currents lower the temperatures of affected areas. In fact, ocean currents moving from one place to another equalize the temperatures.

Latitudes

The temperature of the atmosphere of a particular place near the ground surface depends on the amount of insolation received at that place. Since the amount of insolation received by the ground surface decreases poleward from the equator *i.e.*, from low latitudes towards high latitudes because the sun's rays become more and more oblique (slanting) poleward and hence air temperature also decreases poleward. It may be noted that though sun's rays are almost vertical over the equator throughout the year but there is no maximum temperature on it rather maximum temperature is recorded along 20°N latitude in July because major portion of insolation is reflected by clouds and sizeable amount of heat is lost in evaporation in the low latitude zone (equatorial zone).

Altitude

The temperature decreases with increasing height from the earth's surface at an average rate of 6.5°C per kilometre because of the following reasons.

(i) The major source of atmospheric heat is the earth's surface from where heat is transferred to the atmosphere through the processes of conduction, radiation and convection. Thus, the portion of the atmosphere coming in direct contact with the earth's surface gets more heat from the ground surface than the portion lying above because as we ascend higher in the atmosphere the amount of heat to be transported above decreases and hence temperature decreases aloft,

(ii) The layers of air are denser near the earth's surface and become lighter with increasing altitudes. The lower layer of air contains more water vapour and dust particles than the layers above and hence it absorbs larger amount of heat radiated from the earth's surface than the upper air layers.

Distance From the Coast

The marine environment moderates the weather conditions of the coastal areas because there is more mixing of temperatures of the coastal seas and oceans and coastal lands due to daily rhythm of land and sea breezes. Thus, the daily range of temperature near the coastal environment is minimum but it increases as the distance from the sea coast increases. Minimum daily range of temperature is the characteristic feature of marine climate while extremely high daily range of temperature characterizes continental climate.

(4) Nature of Land and Water

The contrasting nature of land and water surfaces inflation to the incoming shortwave solar radiation largely affects the spatial and temporal distribution of temperature. It may be pointed out that land becomes warm and cold more quickly than the water body. This is why even after receiving equal amount of insolation the temperature of land becomes more than the temperature of the water body. The following reasons explain the differential rate of heating and cooling of land and water.

(i) The sun's rays penetrate to a depth of only 3 feet in land because it is opaque but they penetrate to greater depth of several metres in water because it is transparent to solar radiation. The thin layer of soils and rocks of land, thus, gets heated quickly because of greater concentration of insolation in much smaller mass of material of ground surface. Similarly, the thin ground layer emits heat quickly and becomes colder. On the other hand, the same amount of insolation falling on water surface has to heat larger volume of water because of the penetration of solar rays to greater depth and thus the temperature of ground surface becomes higher than that of the water surface though the amount of insolation received by both the surfaces may be equal.

(ii) The heat is concentrated at the place where insolation is received and there is very slow process of redistribution of heat by conduction because land surface is static. It may be noted that downward distribution of temperature in the land surface within a day (24 hours) is effective upto the depth of only 10 centimetres. Thus, the land surface becomes warm during day and cold during night very rapidly. On the other hand, water is mobile. The upper surface of water becomes lighter when heated by insolation and thus moves away horizontally to other places and the solar rays have to heat fresh layer of cold water. Secondly, heat is redistributed in water bodies by sea waves, ocean currents and tidal waves. All these extend the period of warming of water surface.

(iii) There is more evaporation from the seas and the oceans and hence more heat is spent in this process with the result oceans get less insolation than the land surface. On the other hand, there is less evaporation from the land surface because of very limited amount of water.

(iv) The *specific heat* (the amount of heat needed to raise the temperature of one gram of a substance by 1°C) of water is much greater than the land because the relative density of water is much lower than that of land surface. It means more heat is required to raise the temperature of one gram of water by 1°C than one gram of land.

More specifically, the heat required to raise the temperature of one cubic foot of water by 1°C is two times greater than the heat required for the equal volume of land (one cubic foot). It is apparent that same amount of insolation received by same mass of water and land would increase the temperature of land more than the temperature of equal mass of water.

(v) The reflection (albedo) of incoming solar radiation from the oceanic water surface is far more than from the land surface and thus water receives less insolation than land.

(vi) Oceanic areas are generally clouded and hence they receive less insolation than land surface. But clouds absorb outgoing terrestrial radiation and counter-radiate heat back to the earth's surface. This process retards the loss of heat from the oceanic surfaces and hence slows down the mechanism of cooling of the air lying over the oceans. On the other hand, land surfaces receive more insolation at faster rate because of less cloudiness and simultaneously lose more heat through outgoing terrestrial radiation very quickly.

Nature of Ground Slope

The ground slope facing the sun receives more insolation because the sun's rays reach the surface more or less straight and hence sun-facing ground surfaces record higher temperature than the leeward slopes where sun's rays reach more obliquely. In the northern hemisphere the southward facing slopes of east-west stretching mountains receive greater amount of insolation than the north-ward facing slopes because of their exposure to the sun for longer duration. This is why most of the valleys situated on the southern slopes of the Alpine mountains have settlements and cultivation.

Nature of Ground Surface

The nature of ground surface in terms of colour, vegetation, land use practices etc. affects the distribution of temperature. The snow covered surfaces receive very low amount of insolation because they reflect 70 to 90 per cent of incoming shortwave solar radiation and thus polar and arctic areas are characterized by extremely low temperature through- out the year.

On the other hand, sandy surfaces record high temperature during day time in the tropical and subtropical areas because they absorb most of solar radiation very quickly as they reflect only 20 to 30 per cent of solar radiation. The following is the albedo of different kinds of surfaces.

Table 3.1 : Albedo of different kinds of surfaces

Surface	*Per cent of radiation being reflected*	*Surface*	*Per cent of radiation being reflected*
Snow cover	70-90	Forest	5-10
Sand	20-30	Water	3-5
Grass	14-37	Thick cloud	70-80
Dry ground	15-25	Thin cloud	25-50
Wet ground	10	Black soils	8-14

Dark-coloured ground surfaces receive more solar radiation than light- coloured surfaces. The temperature of ground surface of forested areas never becomes very high because sizeable amount of heat is spent in the process of evapotranspiration from plant leaves.

Prevailing Winds

The prevailing winds help in redistribution of temperature and in carrying moderating effects of the oceans to the adjacent coastal land areas. The winds blowing from low latitudes to high latitudes raise the temperature of the regions where they reach while winds blowing from high latitudes to low latitudes lower the temperature. The winds blowing from oceans to coastal lands bring in marine effects and thus lower the daily range of temperature. The winds coming from higher parts of the mountains lower the temperature in the valleys. The temperature rises at the time of arrival of temperate cyclones while it falls sharply after their passage or their occlusion. The winds associated with warm oceanic currents raise the temperature of coastal lands while the winds coming in contact with cold currents lower the temperature of affected coastal lands. For example, the North Atlantic Drift (extension of Gulf Stream) raises the temperature of coastal areas of north-western Europe and Labrador cold current lowers the temperature in the neighbourhood of New foundland. Some times, local winds change the temperature dramatically. For example, the warm *chioook winds* raise the temperature by 30 to 40°F within a few minutes along the eastern slopes of the Rockies in the USA and the snow melts as by magic at the arrival of chinook. This is why pastures are open throughout the year along the eastern slopes of the Rockies. *Loo*, a local hot wind, raises the temperature in the Ganga Plain of north India to such an extent (maximum temperature ranges between 40°C to 48°C during the day) that heat waves prolong for several days in continuation and several people die of sun stroke.

VERTICAL DISTRIBUTION OF TEMPERATURE

Temperature decreases with increasing height in the troposphere but the rate of decrease varies according to seasons, duration of sunshine and location. On an average, the rate of decrease of temperature with increasing altitudes in a stationary column of air with absence of any vertical motion is 6.5°C per 1000 metres. This decrease of temperature is called vertical temperature gradient or normal *lapse rate* which is 1000 times greater than the horizontal lapse rate (decrease of temperature with increasing latitudes). The decrease of temperature upward in the atmosphere proves the fact that the atmosphere gets heat from the earth's surface through the processes of conduction, radiation and convection. It is, thus, obvious that as the distance from the earth's surface (the source of direct heat energy to the atmosphere) increases (*i.e.*, as the altitude increases), the air temperature decreases. The following are the reasons for decrease of temperature with increasing altitudes in the troposphere.

(i) Heat is transferred to the atmosphere from the earth's surface through the processes of conduction, radiation and convection. Thus, as the altitude increases the amount of heat transported upward decreases. Consequently, every air layer receives less heat than the air layer lying below.

(ii) The air pressure is higher in the lower portion of the atmosphere near the earth's surface because of weight of all the air layers lying above and thus the air density is maximum in the lower atmosphere but it decreases rapidly upward and the air becomes thin.

(iii) The quantity of water vapour, dust particles, water droplets, carbon dioxide etc., which absorb outgoing longwave terrestrial radiation, is more concentrated in the lower portion of the atmosphere and decreases rapidly with increasing altitude. Thus, the temperature of lower atmosphere becomes more than the air layers lying above because of more and more absorption of terrestrial radiation in the lower air layers. In other words, the temperature decreases upward because of decrease of absorption of terrestrial radiation with increasing height in the troposphere.

It may be pointed out that the decrease of temperature with increasing height is confined to the troposphere only. The height of troposphere is 16km and 6 km over the equator and the poles respectively but this height also varies in different seasons *i.e.*,. it becomes higher in summer than in winter. The upper limit of troposphere is called *tropopause*.

It is interesting to note that the temperature at tropopause increases from over the equator towards the poles because the height of tropopause decreases from over the equator towards the poles. The height of tropopause during July and January over the equator is –17km while temperature at the top of tropopause is –70°C. The height of tropopause decreases to 15km in July and 12.5km in January over 45°N latitude but the temperature at the top of tropopause increases to –60°C in July and –58°C in January. The height of tropopause further decreases to 10km in July and 9 km in January over the poles but the temperature increases to –45°C in July and –58°C in January.

Upward from tropopause the temperature is reported to increase with increasing height in the stratosphere wherein it becomes 0°C or 32°F at the height of 50km from sea level. This is the upper limit of the stratosphere and is called stratopause. Temperature again decreases with increasing height in the mesosphere (50km–80km). The temperature becomes –80°C at mesopause, the upper limit of the mesosphere.

Beyond mesopause temperature again increases with increasing height in the thermosphere. It is estimated that the temperature at its upper limit (height undecided) becomes 1700°C. It may be pointed out that this temperature cannot be measured by ordinary thermometer because the gases become very light due to very low air density.

Sometimes, temperature increases with increasing height in the troposphere. In other words, some time warm air lies over cold air. This phenomenon is called *inversion of temperature.*

INVERSION OF TEMPERATURE

Meaning of Temperature Inversion

As stated above temperature decreases with increasing altitudes in the troposphere at an average rate of 6.5°C per 1000 metres (normal lapse rate) but sometimes this normal trend of decrease of temperature with increasing heights is reversed under special circumstances *i.e.,* temperature increases upward upto a few kilometres from the earth's surface. This is called *negative lapse rate.* Thus, warm air layer lies over cold air layer. This phenomenon meteorologically is called inversion of temperature. Such situation may occur near the earth's surface or at greater height in the troposphere but the inversion of temperature near the earth's surface is of very short duration because the radiation of heat from the earth's surface during daytime warms up the cold air layer which soon disappears and temperature inversion also disappears. On the other hand, upper air temperature inversion lasts for longer duration because the warming of cold air layer aloft through terrestrial radiation takes relatively longer period of hours.

Types of Temperature Inversion

Inversion of temperature occurs in several conditions. Some times, it occurs at ground surface while some times, it occurs at greater height. Sometimes, it is caused in the static atmospheric conditions while some times, it occurs due to horizontal or vertical movement of air. Thus, temperature inversion is classified into the following types on the basis of relative heights from the earth's surface at which it occurs and the type of air circulation.

(1) Non-Advectional Inversion

(i) Ground or surface inversion or radiation inversion

(ii) Upper air inversion

(2) Advectional Inversion

(i) Frontal inversion or cyclonic inversion

(ii) Valley inversion due to vertical air movement.

(iii) Surface inversion due to horizontal air movement

(3) Mechanical Inversion

(i) Subsidence inversion

(ii) Turbulence and convective inversion

(1) *Ground surface inversion* also called as *radiation inversion* occurs near the earth's surface due to radiation mechanism. This is also called as non-advectional inversion because it occurs in static atmospheric condition characterized by no movement of air whether horizontal or vertical (it may be noted that air is never

static). Such inversion normally occurs during the long cold winter nights in the snow-covered regions of the middle and high latitudes. In fact, surface inversion is caused due to excessive nocturnal cooling of the ground surface due to rapid rate of loss of heat from the ground through outgoing longwave terrestrial radiation. Thus, the air coming in contact with the cool ground surface also becomes cold while the air layer lying above is relatively warm. Consequently, temperature inversion develops because of cold air layer below and warm air layer above (Fig. 3.2).

The ground surface inversion occurs under the following conditions :

(i) Long winter nights, so that the loss of heat by terrestrial radiation from the ground surface during night may exceed the amount of insolation received from the sun through incoming shortwave electromagnetic radiation waves and thus the ground surface becomes too cold.

(ii) Cloudless and clear sky, so that the loss of heat through terrestrial radiation proceeds more rapidly without any obstruction. Clouds absorb terrestrial radiation and hence retard loss of heat from the earth's surface.

(iii) Presence of dry air near the ground surface, so that it may not absorb much heat radiated from the earth's surface as moist air is capable of absorbing much of the radiant heat from the earth's surface.

(iv) Slow movement of air, so that there is no transfer and mixing of heat in the lower layers of the atmosphere.

(v) Snow-covered ground surface, so that there is maximum reflection of incoming solar radiation. Snow, being bad conductor of heat retards the flow of heat from the ground surface lying below the snow-layers to the lower atmosphere.

Since such inversion of temperature occurs in the static atmospheric condition (very little movement of air) and hence it is also called *static* or *non-advectional in version*. Ground inversion occurs in the low latitude areas (tropical and subtropical areas) during winter nights only and the inversion generally disappears with sunrise but some times it persists upto noon. The inversion occurs upto the height of 30-40 feet in the low latitudes, a few hundred feet in the middle latitudes and half a mile in the high latitudes. It is apparent that the duration and height of surface inversion increase poleward. This inversion promotes stability in the lower portion of the atmosphere and causes dense fogs.

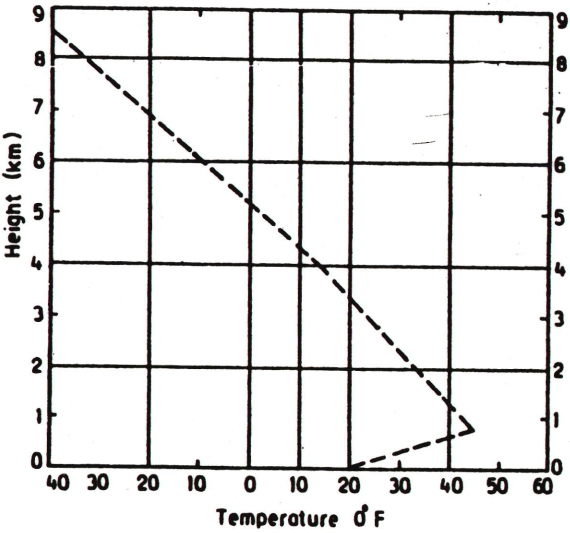

Fig. 3.2: Ground surface inversion of temperature.

(2) *Upper air inversion* is of two types viz. (i) thermal upper air inversion and (ii) mechanical upper air inversion. The thermal upper air inversion is caused by the presence of ozone layer lying between the height of 15 to 35km (even upto 80km) in the stratosphere. The ozone layer absorbs most of the ultraviolet rays radiated from the sun and thus the temperature of this layer becomes much higher than the air layers lying above and below ozone layer. This inversion occurs only when there is no vertical movement of air (either ascent or

descent of air). The mechanical inversion of temperature is caused at higher heights in the atmosphere due to subsidence of air and turbulence and convective mechanism. Such inversion occurs in a number of ways *e.g.*,

(a) Some times, warm air is suddenly transported upward (due to eddies formed by frictional forces) to the zone of cold air and thus cold air being denser lies under the warm air and inversion of temperature is caused,

(b) The descending air is wanned at the dry adiabatic rate of 10°C per 1000m because of compression. This situation causes the existence of warm air above the cold air. Such mechanical inversion caused by the subsidence of air currents is generally associated with the anticyclonic conditions. Such inversion of temperature is of very common occurrence in the middle latitudes where high pressures are characterized by sinking air. The poleward regions of trade winds are also characterized by high pressure caused by the subsidence of air and thus there is also frequent mechanical inversion of temperature. Since the temperature inversion causes stability in the atmosphere and thus there is dry condition. This is the reason that the poleward parts of trade winds are characterized by arid conditions.

(3) *Advectional inversion of temperature* is also called as dynamic inversion because it is always caused due to either horizontal or vertical movements of air. Strong wind movement and unstable conditions of the atmosphere are prerequisite conditions for advectional inversion of temperature. This type is further divided into 3 subtypes on the basis of the nature of air movements *e.g.*, : (i) frontal or cyclonic inversion, (ii) valley inversion due to vertical movement of air, and (iii) surface inversion due to horizontal movement of air.

(i) *Frontal or cyclonic inversion* is caused in the temperate zones due to temperate cyclones which are formed due to the convergence of warm westerlies and cold polar winds in the northern hemisphere. The warm air is pushed up by the cold polar air and thus the warm air overlies the cold air because it is lighter than the cold air. Thus, the existence of warm air above and cold air below reverses the normal lapse rate (decrease of temperature with increasing height) and inversion of temperature occurs. It may be pointed out that contrary to other types of temperature inversion, the inversion layer associated with frontal or cyclonic inversion is always sloping because the coriolis force causes the boundary zone (front) between the warm westerlies and cold polar air masses to become slopy. It is also interesting to note that air moisture increases upward in frontal inversion of temperature while it decreases upward in other types of temperature inversion.

(ii) *Surface inversion* of temperature caused by horizontal movement of air occurs in several situations. Such inversion is caused when warm air invades the area of cold air or cold air moves into the area of warm air because warm air being lighter is pushed upward by relatively denser cold air. When the warm air moves, such inversion is caused over the continents during winter and over the oceans during summer but when the cold air becomes active and invades the areas of warm air, such inversion occurs over the continents during summer and over the oceans during winter. Such surface inversion occurs generally in the low latitudes. The convergence of cold and warm ocean currents also causes such inversion of temperature.

(iii) *Valley inversion* generally occurs in the mountainous valleys due to radiation and vertical movement of air. This is also called vertical advectional inversion of temperature. The temperature of the upper parts of the valleys in mountainous areas becomes exceedingly low during winter nights because of rapid rate of loss of heat from the surface through terrestrial radiation.

Consequently, the air coming in contact with the cool surface also becomes cool. On the other hand, the temperature of the valley floor does not fall considerably because of comparatively low rate of loss of heat through terrestrial radiation. Thus, the air remains warmer than the air aloft and hence the warm and light air of the valley floor is pushed upward by the descending cold and heavier air of the upper part of the valley.

Thus, there is warm air aloft and cold air in the valley floor and inversion of temperature is caused. This situation is responsible for severe frost in the valley floors causing great damage to fruit orchards and vegetables and agricultural crops whereas the upper parts of the valleys are free from frost. This is why the valley floors are avoided for human settlements while the upper parts are inhabited in the mountainous valleys of middle latitudes. Fig. 3.3 explains the mechanism of valley inversion of temperature.

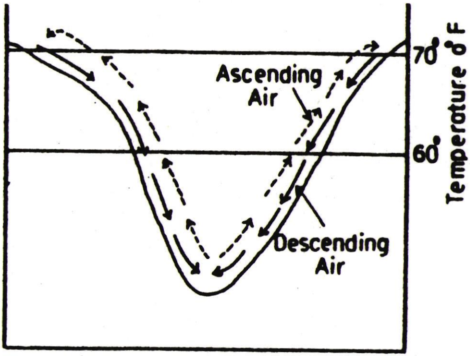

Fig. 3.3 : Valley inversion of temperature.

Significance of Inversion of Temperature

Though, inversion of temperature denotes local and temporary conditions of the atmosphere but there are several climatic effects of inversion which are of great significance to man and his economic activities.

(1) Fog is formed due to the situation of warm air above and cold air below because the warm air is cooled from below and resultant condensation causes the formation

of tiny droplets around suspended dust particles and smokes during winter nights. The smokes coming out of houses and chimneys intensify fogs and become responsible for the occurrence of urban smogs. When smog is mixed with air pollutants such as sulphur dioxide it becomes poisonous and deadly health hazard to human beings. The incidents of deadly urban smogs of December 1930 in Meuse Valley of Belgium (600 people fell ill and 63 people died), of October 26, 1948 at Donora in Pennsylvania (USA), and of 1952 in London (causing 4000 human deaths) tell the ordeal of urban smogs. Fogs are also formed at the convergence of warm and cold ocean currents. For example, dense and extensive fogs are formed near Newfoundland due to convergence of warm Gulf Stream and cold Labrador current. Fogs reduce atmospheric visibility and thus they are responsible for several cases of accidents of air crafts while taking off and landing and ships in the oceans. Road and rail transport is also badly affected by the occurrence of dense fogs. Though, generally fogs are unfavourable for many agricultural crops such as grams, peas, mustard plants, wheat etc. but some times they are also favourable for some crops such as coffee plants In Yemen hills of Arabia where fogs protect coffee plants from direct strong sun's rays.

(2) Inversion of temperature causes frost when the condensation of warm air due to its cooling by cold air below occurs at temperature below freezing point. Frost is definitely economically unfavourable weather phenomenon mainly for crops because fruit orchards and several agricultural crops such as potatoes, tomatoes, peas etc. are totally damaged over-night. There are frequent cases of destruction of fruit orchards in the lower parts of valleys due to severe frost caused by inversion of temperature in California (USA). Fruit orchards were severely damaged in California in the year 1913, 1917 and 1923 due to severe frosts. The valley floors in the hills of Brazil are avoided for coffee cultivation because of frequent frosts. Alternatively,

coffee is planted on the upper slopes of the valleys. The upper parts of the valleys are inhabited in Switzerland while lower parts are avoided. In fact, the upper slopes of valleys are characterized by fruit orchards, hotels and motels (for tourists), various resort centres etc. while the lower slopes are deserted.

(3) Inversion of temperature causes atmospheric stability which stops upward (ascent) and downward (descent) movements of air. The atmospheric stability discourages rainfall and favours dry condition. The inversion of temperature caused by the subsidence of air resulting into anticyclonic conditions increases aridity. This is why the western parts of the continents situated between 20°-30° latitudes and characterized by anticyclonic condition represent most widespread tropical deserts of the world.

HORIZONTAL DISTRIBUTION OF TEMPERATURE

On an average, temperature decreases from the equator towards the poles and thus low latitudes are characterized by highest temperature whereas high latitudes record lowest temperature. It may be noted that highest temperature is never recorded at the equator instead it is recorded near the tropics of Capricorn and Cancer because a sizeable portion of incoming solar radiation is reflected by clouds and a large part of heat is spent in the process of evaporation near the equator. On the other hand, most of the incoming solar radiation reaches the ground surface due to clear sky near the tropics of Cancer and Capricorn.

Normally, temperature decreases from equator towards the poles. This change of temperature rather decrease of temperature poleward is called *temperature gradient*. The rate of decrease of temperature between the tropics of Cancer and Capricorn is rather low and therefore temperature gradient is insignificant but temperature decreases more rapidly from the tropics poleward and therefore temperature gradient is also very high. The horizontal distribution of temperature is represented and studied with the help of isotherms.

Isotherms

The lines drawn on maps joining the places of equal temperature reduced to sea level are called *isotherms*. It is necessary to reduce the actual temperatures of all places at sea level before drawing isotherms. It is, thus, obvious that isotherms do not represent the real temperature of the places through which they pass rather they show temperature of the places at sea level. This is why the isotherm maps are not useful for farmers because they need real temperature of a particular face for growing crops. Normally, isotherms run east-west and are generally parallel to latitudes.

This trend shows strong control of latitudes on the horizontal distribution of temperature. Generally, isotherms are straight but they bend at the junction of continents and oceans due to differential heating and cooling of land and water. Isothermal lines are more irregular in the northern hemisphere because of large extent of continents but they are more regular in the southern hemisphere due to over-dominance of oceans.

Isotherms are generally closely spaced in the northern hemisphere but they are widely spaced in the southern hemisphere. The closely spaced isotherms denote rapid rate of change of temperature and steep temperature gradient. On the other hand, widely spaced isotherms indicate slow rate of temperature change and low temperature gradient. On an average, isotherms trending from land towards the ocean bend equatorward during summer and poleward during winter.

On the other hand, isotherms trending from the oceans to the continents bend poleward during summer and equatorward during winter. The isotherms during the months of January and July are taken as representatives for the study of horizontal distribution of temperature during winter and summer seasons respectively because they represent seasonal extremes.

July and January

If we look at the world map representing horizontal distribution of temperature in January and July (Figs. 6.3 and 6.4) the following facts come to light:

(1) The months of July and January are warmest and coldest in the northern hemisphere whereas the warmest and coldest months in the southern hemisphere are January and July respectively.

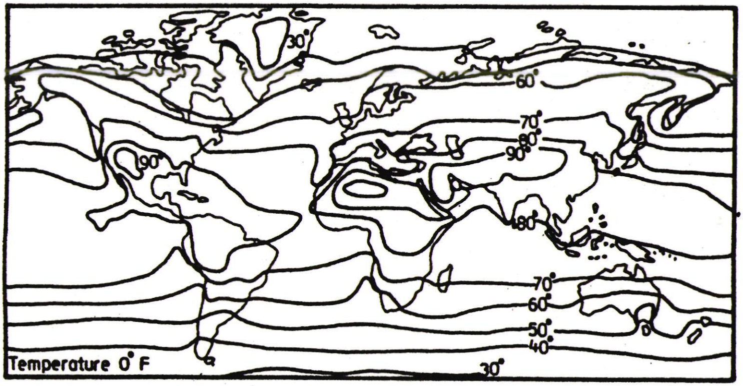

Fig. 3.4 : Isotherms representing horizontal distribution of temperature in July.

(2) Both the maps (Figs. 6.3 and 6.4) show latitudinal shifts of isotherms in accordance with seasonal shifting of overhead sun but this shifting of isotherms is more pronounced on the continents.

(3) The maximum temperatures in January and July are always recorded on the continents. Minimum temperature in January is observed in Asia and North America.

(4) January isotherms suddenly bend poleward while passing through warm portions of the oceans and bend equatorward while passing through the cold portions of the oceans in January in the northern hemisphere while the trend is opposite in July, On the other hand, the isotherms are more or less regular and straight in the southern hemisphere because of over-dominance of oceans.

(5) Temperature gradient is more pronounced during winter than summer.

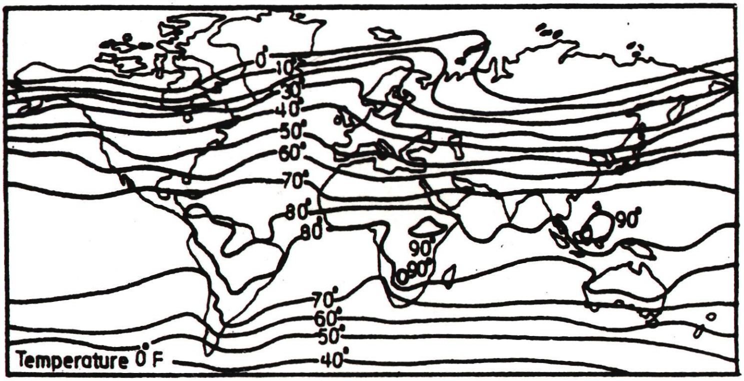

Fig. 3.5 : Isotherms representing horizontal distribution of temperature in January.

REGIONAL DISTRIBUTION OF TEMPERATURE

According to ancient Greek thinkers the globe is divided into three temperature zones on the basis of latitudes (Fig. 3.6) *e.g.,*:

(1) Tropical zone,

(2) Temperate zone, and

(3) Frigid zone.

(1) *Tropical zone* extends between the tropics of Cancer (23.5°N) and Capricorn (23.5°S). The Sun's rays are more or less vertical on the equator throughout the year. The remaining areas are also characterized by vertical sun's rays at least once every year.

There is no winter around the equator because of high temperature prevailing throughout the year but as one approaches the tropics of Cancer and Capricorn summer and winter are clearly observed and differentiated.

(2) *Temperate zone* extends between 23.5° and 66.5° latitudes in both the hemispheres. Though, the duration of day and night is longer in this zone but it is never more than 24 hours. There are marked seasonal contrasts with the northward and southward (summer and winter solstices)

migration of the overhead sun and thus the range of temperature between summers and winters becomes exceptionally very high.

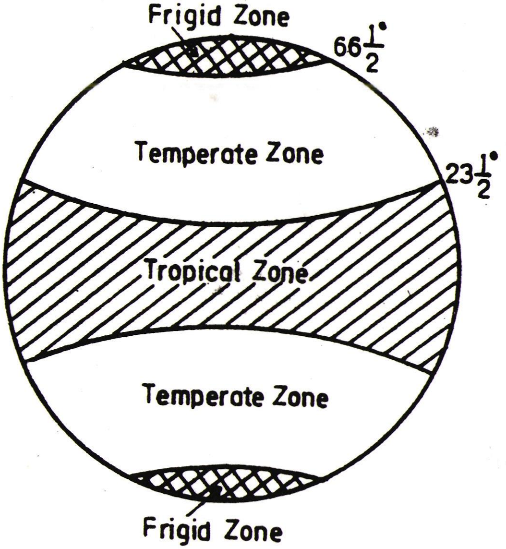

Fig. 3.6 : Temperature zones according to the views of ancient Greek thinkers.

(3) *Frigid zone* extending between 66.5° latitude and the poles in both the hemispheres is characterized by more oblique sun's rays throughout the year resulting into exceptionally very low temperature. The length of day and night is more than 24 hours. Days and nights are of 6 months duration at the poles. Sun is never vertical and the ground is covered with snow as temperature more or less remains below freezing point.

It may be pointed out that the Greeks gave undue importance to latitudes in determining different temperature zones and overlooked the controls of contrasting nature of continents and oceans in terms of their heating and cooling, prevailing winds, ocean currents, nature of ground surface etc. Taking all these factors in consideration Soupan divided the globe into temperature zones on the basis of isotherms. According to him the outer limit of tropical zone should be determined on the basis of annual isotherm of 68°F (20°C). The boundary between temperate and frigid zones in the northern hemisphere should be demarcated by 50°F (10°C) isotherm of July while January isotherm of 50°F(10°C) should separate temperate zone from the frigid zone in the southern hemisphere.

WORLD TEMPERATURE DISTRIBUTION

The seasonal distribution of temperature forms one criterion in the delimitation of climatic types. Sea-level isothermal maps show for the northern hemisphere in winter a marked northward bend in the isotherms over the sea and a southward bend over the land; trace particularly the course of the 0°C (32°F) isotherm. In summer the isotherms bend northward (but not so markedly) over the land. In the southern hemisphere, where the land areas are small, the parallel east-west trend of the isotherms is more in evidence, particularly south of 35°S.

The highest shade temperature recorded in the world was 58°C (136-4°F) at Azizia in Tripoli (1922) and again in San Luis Potosi in Mexico (1933), the highest in Britain 38°G (100-5°F) at Tonbridge, Kent (1868). Conversely, the world's lowest recorded shade temperature was –88°C (–127°F) at Vostok in the Antarctic (1960), the lowest in Britain –27.2°C (–17°F) at Braemar (1895).

'*Sensible temperatures*' are the sensations of heat and cold felt by the human body. Temperature in this connection is intimately related to humidity; dry heat mitigates high temperatures by accelerating evaporation from the skin surface, while moist heat makes the body feel distinctly uncomfortable. An index of this is the wet-bulb *thermometer*; if the wet-bulb reads much above 24°C (75°F), sustained manual labour is extremely difficult. Damp raw cold is much more trying than dry cold; damp air is a better conductor of heat than dry air, and allows the escape of heat from the body in cold weather. Very low temperatures can be endured (as in central Canada) when the air is dry and still and the sun shining. A *temperature-humidity index* can be constructed by various empirical formulae which affords an indication of the effects on human comfort; on one such scale the index of 60 to 65 represents ideal conditions, while 80 can be regarded as so uncomfortable (as happens in

New York and elsewhere) offices and factories may be closed. Another physiological index in cold climates is *windchill*, obtained from a formula involving both temperature and wind force.

These facts are of prime importance to the geographer; they involve problems of tropical and low-altitude settlement, of white acclimatization in the tropics, of the exploitation of the Northland, and of the efficiency of labour.

Accumulated Temperatures

The calculation of accumulated temperatures is a statistical device for indicating the accumulation of warmth over a basic critical value for a certain period of time. This has considerable significance in the study of relationships between plant activity and temperature conditions during the period of growth, in the classification of climatic types, and in the analysis of climatic cycles.

The unit used is called either the degree-day or day-degree, which gives an exact measure of the departure of the mean daily figures from the selected base-temperature. Thus, if 6°C is the datum, and 9°C is the mean for a specific month, it will count as $3 \times 31 = 93$ degree-days towards the final total. More accurately, though more tediously, the accumulated temperature for a specific day may be given in degree-hours.

SUNSHINE

The duration of sunshine is partly a function of latitude, for the hours of light (that is, of possible sunshine) vary with the seasons in different latitudes. It is also a function of daytime cloudiness.

Measurement and Recording

The duration of bright sun-shine is measured by means of a Campbell-Stokes recorder, a solid sphere of glass 10 cm in diameter. This focuses the rays of sunshine on to a sensitized card graduated in hours, and so burns a line during the time the sun is shining. Faint sunlight, near dawn or dusk, or when the sun is partially obscured, is not recorded. When mean figures have been obtained over the requisite number of years, the values for each station can be plotted, and lines of equal mean duration of sunshine (isohels) can be interpolated.

Distribution of Sunshine

The sunniest parts of the earth are the hot deserts in the Trade Wind belt. At Helwan Observatory, in the Nile valley south of Cairo, the mean sunshine for the year is 3668 hours, which represents about 82 per cent of the possible amount for that latitude. From June to September the duration is about 90 per cent of the possible amount, and even the cloudiest month (January) receives 70 per cent of the possible. The lands around the Mediterranean Sea and other parts of the world with broadly similar climates enjoy an extremely sunny summer, with a mean of about 90 per cent of the possible duration. Even in winter, the rainy season, days without any sun-shine are few, since the rain tends to be shortlived.

SCALE OF TEMPERATURE

The temperature can be measured in terms of the expansion or contraction in length of a column of liquid as the result of heating or cooling. These changes have been standardized in the form of certain scales; on the *Fahrenheit* scale the boiling-point of water is fixed at 212°, its freezing-point at 32°. The equivalent points on the *Centigrade* (since 1948 officially called Celsius) scale are 100° and 0°, on the Reaumur scale 80° and 0°. Scientists sometimes use the *Absolute* or *Kelvin* scale, in which temperature is measured in degrees Centigrade from the point at which molecular movement ceases, –273-15°C = 0°K.

Instruments

The column of liquid in a thermometer, the instrument used for measuring temperature, is of either mercury or alcohol. Thermometers must be carefully sited; very different readings will be obtained on the ground ('grass temperatures'), at various depths beneath the surface (usually 10 cm, 20 cm, 30 cm and 1 m), on a brick wall, or in the shade. The records usually required are of actual air temperatures—that is, 'shade temperatures'—measured under standardized conditions with precautions to exclude the direct rays of the sun; these are the figures generally quoted by climatologists. The thermometer is placed in a meteorological screen (a wooden box with a double top and bottom and louvred sides, in which the bulb of the thermometer is 1.25 m (4 ft) from the ground). The screen is carefully sited away from buildings.

Maximum and *minimum thermometers* are of great value, in which small dumb-bell-shaped markers indicate the highest and the lowest temperatures attained since the last setting, which is done each 24 hours with a small magnet. Most convenient is the thermograph, the principle of which is the expansion and contraction of a bi-metallic strip in the shape of a coil; one end is fixed, the other actuates a pen which traces a continuous record on a chart fixed to a revolving drum. Another type of thermograph is the Bourdon tube, used in aircraft, in which a curved metal tube is filled with spirit; its curvature changes with the temperature, and these changes are recorded on a chart or dial.

Presentation of Temperature Records

Temperature figures may be presented in several ways. Extreme data are sometimes interesting (as when the Meteorological Office announces that it has been the warmest day in January for seventy years). Extreme maxima and minima, the incidence of frost, and other crucial figures are also of value.

The temperature figures of most value to climatologists seeking to present a long-term view of average conditions are means, with varying corrections and weightings. Diurnal, monthly and annual means are all used, but the most useful are the mean temperatures of the warmest and coolest months respectively over a minimum thirty years of observation. From these can be computed the mean range, that is, the difference between the means of the warmest and coolest months. The range is 31°C (56°F), indicative of the great seasonal climatic contrasts in northern China. The annual mean is 12° C (53°F), yet ten of the twelve months. The annual mean for Verkhoyansk in Siberia is –16° C (2-7°F), but this is of little significance when we learn that the means of the coldest and warmest months are –51°C (–58°F) and 16°C (60°F).

ISANOMALOUS TEMPERATURE

The difference of observed temperature of a place and the mean temperature of the latitude passing through that place is called *thermal anomaly*. For example, if the average temperature of 30°N latitude is 20°C and the temperature of 'A' place located on that latitude is 30°C, then the thermal anomaly is of 10°C. If the observed temperature of a particular place is more than the mean temperature of the latitude of that place, the thermal anomaly is called *positive thermal anomaly* but if the observed temperature of a given place is less than that of the latitude of that place then it becomes *negative thermal anomaly*. The equal thermal anomaly of several places is called *isanomalous temperature* and the lines drawn on the world map joining places of equal thermal anomaly are called *isanomals*.

TEMPERATURE FACTORS

Insolation

The main source of heat affecting the atmosphere and the earth's surface is the radiant energy (*solar radiation*) which travels through space from the sun (a mass of intensely hot gases, with a temperature estimated to be at its surface about 6000°C), in the form of electro-magnetic energy. The earth receives only a very small part of the total radiation, perhaps one two-thousand-millionth, but this is vital for the earth. This solar or radiant energy is known as insolation. At the outer limit of the atmosphere the solar radiation consists of visible light rays (about 41 per cent of the total), very short gamma rays, alpha rays, X-rays and ultraviolet rays (9 per cent), and the longer infrared and heat rays (50 per cent).

The measure of the intensity of insolation per unit area received at the outer limit of the atmosphere is called the *Solar Constant*, which is calculable. This is equal to nearly 2 gramme-calories per square cm per minute; *i.e.*, the radiation received each minute on a surface area of a square cm could raise the temperature of 1 gramme of water through 2°C (or alternatively equivalent to 1.4 kilowatts per sq m). In point of fact, this term seems to be a misnomer, since radiation does seem to vary, as evidenced by sun-spot activity, though only by about 1-2 per cent. Moreover, the earth has an elliptical orbit around the sun, so that it is at its farthest point on July 4 (a position known as aphelion, at a distance of 152 million km (94.5 million miles), and at its nearest on 3 January (*perihelion*, at a distance of 147 million km [91.5 million miles)]. The amount of solar energy received is therefore about 6 per cent more at the perihelion, and it would seem that as this occurs in the northern hemisphere winter, that season should be slightly milder than in the southern hemisphere. Actually, other factors, notably the greater speed of the earth along its orbit in December-January due to the curvature of its ellipse, and the great area of land in the northern hemisphere, completely mask this effect.

What really matters is the effect on the insolation when it enters the earth's atmosphere and in part passes to the earth's surface. Some 19 per cent is directly absorbed by the atmosphere, particularly by the carbon dioxide and water-vapour present; this proportion is so low because the short light-waves pass, with little check, through the atmosphere. A small amount (9 per cent) is lost as a result of diffuse reflection ('scattering') caused by air molecules and dust particles; this scattered radiation is not converted into heat. The scattering effect is greatest for the rays of light at the short-wave end of the spectrum, the blue and violet end, which helps to explain the colour of the sky. A small amount, by contrast, is down-scattered towards the earth's surface. A serious loss of insolation (25 per cent) is involved in that amount reflected directly back into space from both clouds and the ground; the radiation coefficient of the latter is termed its albedo. The drop in temperature experienced when a cloud passes across the sun can be very appreciable, and a thick 'overcast' can locally and temporarily reduce incoming insolation by as much as 80 per cent. On an average, however, about 53 per cent of incoming insolation is lost.

The balance (about 47 per cent) reaches the earth's surface to be converted into heat energy. As the surface warms, it re-radiates some of this energy, but in the form of long-wave heat radiation, equivalent to 14 per cent of the total insolation initially received. Clearly if this re-radiation did not occur, the surface would become progressively hotter. These long waves are more readily absorbed by the atmosphere than are the incoming short waves, and so the atmosphere is indirectly heated. It is also warmed by the transfer of latent heat as a result of evaporation and condensation equivalent to about 23 per cent of the total energy involved. Finally, the heated surface of the earth warms the layer of air resting upon it by direct conduction (10 per cent), which may continue as a vertical heat transference within the atmosphere known as convection', this is manifest as a rising air current, updraught, convection cell or popularly 'thermal'.

The surface of the earth therefore both absorbs and gives out radiant energy at the same time, although in the form of energy of different wavelengths; as a result the heating depends on the balance between the two (Fig. 6.7). During a clear, sunny day in summer there is a net gain and the temperature rises, reaching a maximum in the early afternoon. During the night, incoming insolation ceases, while the outgoing radiation continues. There is, therefore, a loss of heat during the night, and the coldest period is just after dawn.

The atmosphere acts rather like a greenhouse roof, since long-wave radiation cannot pass out through it as readily as incoming short-wave insolation. Something like seven-tenths of the outgoing radiation is absorbed by the atmosphere, otherwise temperatures would drop more markedly during the night and in winter. This insulating effect is increased by a cloud-cover. Hard frosts in winter occur during a clear, starlit night, when the outgoing radiation into space is at its maximum. Similarly, in the tropical deserts with their cloudless skies, terrestrial radiation at night causes a sharp fall in temperature. In California and elsewhere 'smudging' is used to combat nocturnal cooling; fires giving off dense palls of smoke check radiation and so reduce frost incidence at blossom-time.

Twilight Particles of dust and water-vapour in the earth's atmosphere reflect the sun's light before it has appeared above the horizon in the morning and after it has disappeared below it in the evening. Astronomical twilight lasts from when the sun is 18° below the horizon until dawn, and again from sunset until the sun is 18° below the horizon. The more limited civil twilight extends only from 6° and to 6° respectively. In high latitudes the low slant of the sun's path as it dips or rises causes twilight to be prolonged as compared with low latitudes. At the North Pole twilight persists continuously from 23 September to 14 November, and then again from 29 January to 21 March, that is, during the time when the sun's declination is changing from 18° to 0° and back again; in between is a period of complete darkness.

The Nature of the Surface

So far the value of insolation has been discussed as if it were affecting a homogeneous surface. The basic difference as far as the world is concerned is between land and water surfaces.

The specific heat of a substance is defined as the number of calories required to raise the temperature of 1 gramme of that substance through 1°C; a calorie represents the amount of heat required to raise the temperature of 1 gramme of water through 1°C. On this basis the specific heat of seawater is 0.94 and of granite about 0.2; in other words, water must absorb nearly five times as much heat in order to increase in temperature by the same amount as earth. Land surfaces therefore heat up more rapidly and intensely than do water surfaces. On the other hand, land cools more rapidly when the source of heating is cut off.

Other factors emphasize this contrast. Solid earth is a bad conductor, hence a shallow layer is more intensely heated. The earth is opaque, while water allows the rays to penetrate to a greater depth and so affect more water to a lesser extent. The daily fluctuations in temperature may be detected 15-18 m (50-60 ft) below the surface of water, but not more than a metre below the surface of the ground. A water surface allows evaporation, which is a cooling process, and there is also a considerable heat transference through mixing by convection currents readily set up in water. It reflects a high proportion of the light rays (compare burnished silver, which remains cool under the hottest sun because it reflects 95 per cent of the rays), while darker earth substances absorb more. A piece of black paper left on the surface of a snowfield will in a few hours have sunk to a depth of several cm because it has absorbed heat and so melted the snow around.

A snowfield reflects a large proportion of the rays, so that the snow remains while skiers become bronzed in the brilliant sun-shine; the polar ice-caps are virtually perfect reflectors. The ratio between the total solar radiation falling upon a surface and the amount reflected, expressed as a decimal or a percentage, is known as the reflection coefficient or albedo. The earth's average albedo as seen from space (including also the *albedo* of the clouds) is about 0.4; *i.e.,* four-tenths of the solar radiation is reflected back into space. Surface albedo varies from 0.03 for dark soil to 0.8 for a snowfield.

Water has a low albedo (0.02) with near vertical rays, though a high one for low-angle slanting rays, and grass has about 0.25. Dry sandy soils have a low specific heat and warm up rapidly at the surface, although, the insulating effect of the air contained between the particles causes the heat to be retained at the surface, so that the sand only a few cm below may be as much as 15°C cooler. Swamps or waterlogged soils act like a water surface, and forests modify heating by casting shade. Microclimatology presents many examples of these variations; compare these records, taken on Salisbury Plain in June 1925, of air temperatures just above various surfaces:

	Temperature				
	°C	°F		°C	°F
Shade (air)	22	71	Bare earth	35.5	96
Macadam road	43	109	Grassland	29	85
Sand	35	95	Brick rubble	31	88

The climatological results of differential heating of land and water result in both diurnal and seasonal contrasts. The decrease in temperature during a summer night as a result of outgoing radiation is only one-quarter as great in a given volume of water as in the same volume of earth. Consequently a water surface is subject to a much smaller diurnal range.

Thermals

When heating of the earth's surface is localized as a 'hot spot' (as over a road, patch of Tarmac or bare earth, as compared with a thick vegetation cover), the rising updraught is known as a thermal or 'convection cell', which both birds and glider-pilots may use to assist their ascent.

As a thermal develops, it seems to take the form of a vortex ring, with convergent air rotation within it. Rarely are the hot spot and resulting rising air column continuous; usually thermals comprise individual bodies or 'bubbles' of turbulent ascending air. There may be, it is true, some steady thermal sources on warm, windless days of anticyclonic conditions, but more usually there is a general turbulent zone in the air near the ground from which thermals are 'triggered off' at intervals.

Winds

The effect of winds on temperature is to 'transport' temperatures prevailing in the areas over which they blow, either from land or sea. The result of exposure to, or shelter from, cold out blowing winds from continental interiors has been mentioned. Onshore winds in the Tropics, blowing from over the cooler ocean, tend to modify temperatures on the coastal margins. On the other hand, onshore winds such as the Westerlies may in winter carry mild temperatures from over the oceans on to the continental margins. Local winds (the warm sirocco, the cold mistral and bora, and the foehn or chinook winds on the lee side of mountains) may produce rapid temperature changes.

Relief

One immediate relief influence on temperature has been mentioned—the effect of altitude. The environmental lapse-rate is about 0·6°C per 100 m (3.3°F per 1000 ft), but there are considerable variations from this figure. During the period 1884-1903, when an observatory was maintained on the summit of Ben Nevis at 1343 m (4406 ft), the mean annual temperature was –0.25°C, compared with 8°C (47°F) at Fort William near sea-level. In the British Isles the lapse-rate averages 0.6°C per

133 m (1°F per 410 ft) in winter, but increases to 0-6°C per 90m (1°F per 270 ft) in summer.

It must of course be remembered that there may be a considerable difference between a 'free-air' lapse-rate and a 'relief lapse-rate. Both tend to decrease by night and increase by day. Much more important variations are found when vertical movements of air occur. However, the environmental lapse-rate is of practical importance. Thus, Delhi, in the Indo-Gangetic plain at a height of 219 m (718 ft), has a mean June temperature of 33°C (92°F), but at its hill-station, Simla (2204 m, 7232 ft), the corresponding temperature is only 19°C (67°F).

Other relief controls of temperature involve shelter and aspect. Shelter protects an area from cold winds; compare, for example, the bleak cold which may be experienced at the mouth of the Rhone when the mistral is blowing, with the mild Riviera coast to the east sheltered by the *Maritime Alps*.

On a larger scale, southern China experiences abnormally low winter temperatures because it is exposed to the cold out blowing monsoon from which India is protected by the wall of the Himalayas. America has no real transverse barrier, so that New Orleans may experience 'cold snaps' brought by air streams from the Arctic, while very warm humid airstreams from the Gulf of Mexico may bring heat-waves to the northern states and even into Canada.

Aspect, including both the direction and degree of slope, is important, since a southern aspect in the northern hemisphere means greater insolation. A striking contrast in temperature, vegetation and human use is seen on the shady and sunny sides of an Alpine valley.

Inversion

One striking exception to the decrease of temperature with altitude is where an inversion occurs. During clear, settled weather, as radiation of heat takes place during the night, the air on hill-slopes is rapidly cooled, and this dense air drains downward, filling valleys or basins with cold air, possibly at temperatures below freezing, when the upper slopes are markedly warmer.

Miles City, Montana, at a height of 703 m (2371 ft) in a deep hollow in the Great Plains, has experienced the lowest temperature ever recorded in the U.S.A. (excluding Alaska), –54°C (–65°F). Yet the summit of Pike's Peak (4300 m, 14,109 ft) has never recorded a temperature below –40°G (–40°F).

Frost may cause serious losses to fruit-cultivators if it occurs during the critical blossom-time; the plum-growers of the Vale of Evesham, the viticulturalists of the Gironde and the Champagne districts, and the citrus-fruit growers of California alike face the problem. Smudging with dense clouds of smoke, carefully maintained oil-heaters among the trees, and even flooding with water to check the rate of cooling and to stimulate light fogs, are used.

In southern France, where early vegetables (primeurs) are grown, the fields are covered before sundown with light straw mats, though not to exclude frost so much as to keep in ground warmth. The best method is to avoid 'frost pockets' by siting orchards on slopes away from lines of cold air drainage.

Inversions also occur as the result of the relative position of air-masses of different temperatures associated with local pressure systems. In addition to what might be called 'surface' or 'ground' inversions, similar phenomena sometimes occur at high altitudes. Their importance is that they tend to prevent vertical movement of air, hence inducing a state of stability, and so there is unlikely to be any rainfall.

The Isothermal Layer

Under very stable high pressure conditions, the temperature may remain the same within a layer of air extending to a considerable height.

4

SOIL

INTRODUCTION

Soil is the thin surface-layer on the earth, comprising mineral particles formed by the break- down of rocks, decayed organic materials, living organisms, water and air. Soil is formed under specific natural conditions and each of the elements of the natural environment contributes to this complex process, described by the soil scientists as the process of *pedogenesis*.

Soil is a very important natural resource of India because agricultural production is basically dependent on the fertility of soil. The rich deep fertile soils of the Ganga Plain, especially its delta, and coastal plain of Kerala support high density of population through agricultural prosperity. On the other hand, the shallow and coarse grained soils of Telangana and Rajasthan support only small population because these soils do not provide a base for prosperous agriculture.

SOIL FORMATION IN INDIAN CONDITIONS

Soil formation is mainly related the parent rock material, surface relief, climate and natural vegetation. Animals, insects and man also play important role in soil formation. Some of the important factors of soil formation are mentioned below:

Climate

Climate is the most important single factor in soil formation. Most important climatic factors affecting soil formation are the amount and seasonal distribution of temperature and rainfall. Climate controls the type and effectiveness of weathering of the parent material, the quantity of water seeping through the soil and the type of micro-organisms present therein. When the climatic control acts for a sufficiently long period, it reduces the differences in the parent materials. Two different parent materials may develop the same soil in the same type of climate. Similarly, the same parent material may produce two different types of soils in two different types of climates. The crystalline granites produce laterite soil in relatively moist parts of the monsoonal region and non-laterite in drier areas.

The heat combined with the rate of alteration between wet and dry intervals of monsoon climate is the basic course. Hot summer and low rainfall develops black soil as is found in some parts of Tamil Nadu irrespective of the parent rock. In Rajasthan, both granite and sandstone give birth to sandy soil under arid climate. This soil is poor in organic matter.

Natural Vegetation

Natural vegetation reflects the combined effects of relief and climate. The formation and development of soil is very much influenced by the growth of vegetation. The decayed leaf material adds much needed *humus* to soil thereby increasing its fertility. The densely forested areas contain some of the best soils in India. There is a close relationship between the vegetation types and soil types in India.

Parent Material

The material for soil formation is mainly derived from the rocks and is termed as the parent material by soil scientists. The surface rocks are exposed to the process of weathering and suffer decay and decomposition. In this process, the rocks are converted into fine grains and provide a base for the soil formation. The soils of the Northern Plain of India have been largely derived from the depositional work of the Himalayan rivers. This depositional work has been continuing for thousands of years. These are alluvial fertile soils consisting of fine silts and clay. These soils have little relation with the original rocks. On the other hand, the soils of peninsular plateau are generally coarse-grained and are closely related to the parent rocks. The peninsular soils are generally less fertile.

Relief

Relief influences the process of soil formation in many ways, the most important being the slope of land. Steep slope encourages the swift flow of water and hinders the process of soil formation. There may even be soil erosion in areas of steep slope. Chambal ravines offer an important example of soil erosion. The areas of low relief or gentle slope generally experience deposition and have deep layer of soil. Because of this reason, there are thick layers of fertile alluvial soils in the northern plain of India whereas the soils are generally shallow in the plateau area. The exceptions in the plateau are river basins where the soil layers are sufficiently deep. The degree of slope also largely determines the fertility of soil.

MAJOR SOIL GROUPS OF INDIA

India is a country of vast dimensions with varied conditions of geology, relief, climate and vegetation. Therefore, India has a large variety of soil groups, distinctly different from one another. Different criteria have been applied to classify Indian soils, the outstanding being geology, relief, fertility, chemical composition and physical structure, etc. Any classification based on any one of the aforesaid criteria has its own inherent drawback. Even the most competent pedologist would find it difficult to present an accurate, complete, comprehensive and generalised account of the Indian soils.

Geologically, Indian soils can broadly be divided into two main types:

(a) Soils of Peninsular India and

(b) Soils of Extra-Peninsular India.

The soils of Peninsular India are those which have been formed by the decomposition of rocks *in situ, i.e.,* directly from the underlying rocks. They are transported and redeposited to a limited extent and are known as sedentary soils. On the other hand, the soils of the Extra-Peninsula are formed due to the depositional work of rivers and wind. They are mainly found in the river valleys and deltas. They are very deep and constitute some of the most fertile tracts of the country. They are often referred to as *transported or azonal soils.*

The Indian Council of Agricultural Research (ICAR) set up an All India Soil Survey Committee in 1953 which divided the Indian soils into eight major groups. They are :

(1) Alluvial soils,

(2) Black soils,

(3) Red soils,

(4) Laterite and Lateritic soils,

(5) Forest and Mountain soils,

(6) Arid and Desert soils,

(7) Saline and Alkaline soils, and

(8) Peaty and Marshy-soils.

1. Alluvial Soils

Alluvial soils are by far the largest and the most important soil group of India. Covering about 15 lakh sq. km. or about 45.6 per cent of the total land area of the country, these soils contribute the largest share of our agricultural wealth and support the bulk of India's population. Most of the alluvial soils are derived from the sediments deposited by rivers as in the Indo-Gangetic plain although some alluvial soils in the coastal areas have been formed by the sea waves. Thus, the parent material of these soils is all of transported origin. The streams bring with them the products of weathering of rocks from the mountains and deposit them in the low-lying areas. The alluvial soils are yet immature and have weak profiles. They differ in consistency from *drift sand to rich loams and from silts to stiff clays.* A few occasional kankar beds are also present. However, pebbly, stony or gravelly soils are rare in this group. The chemical composition of the alluvial soils make this group of soils as one of the most fertile in the world. The proportion of nitrogen is generally low, but potash, phosphoric acid and alkalies are adequate, while iron oxide and lime vary within wide range. The porosity and texture provide good drainage and other conditions favourable for bumper crops. These soils are easily replenished by the yearly river floods and support uninterruped crop growth.

The widest occurrence of the alluvial soils is in the Great Indo-Gangetic Plain starting from Punjab in the west to West Bengal and Assam in the fast. They also occur in deltas of the Mahanadi, the Godavari, the Krishna and the Cauvery, where they are called deltaic alluvium. Along the coast they are known as coastal alluvium. Some alluvial soils are found in the Narmada and Tapi Valleys. Northern parts of Gujarat also have some cover of alluvial soils.

Geologically, the alluvium of the Great plain of India is divided into newer or younger khadar and old bhangar soils.The *khadar* soils are found in the low areas of valley bottom which are flooded almost every year. They are pale brown, sandy clays and loams, more dry and leached, less calcareous and carbonate *i.e.* they are less *kankary*. *Bhangar*, on the other hand is found on the higher reaches about 30 metres above the flood level. It is of a more clayey composition and generally dark coloured. A few metres below the surface of the bhangar are beds of lime nodules known as *kankar*. Along the Shiwalik foothills, there are alluvial fans having coarse, often pebbly soils. This zone is called bhabar. To the south of the *bhabar* is a long harrow strip of swampy lowland with silty soils. It covers an area of 56,600 sq. km. and is called *tarai*. The tarai soils are rich in nitrogen and organic matter but are deficient in phosphate. These soils are generally covered by tall grasses and forests but are suitable for a number of crops such as wheat, rice, sugarcane, jute and soyabean under reclaimed conditions.

Due to their softness of the strata and fertility the alluvial soils are best suited to irrigation and respond well to canal and well/tube-well irrigation. When properly irrigated, the alluvial soils yield splendid crops of rice, wheat, sugarcane, tobacco, cotton, jute, maize, oilseeds, vegetables and fruits.

2. Black Soils

The black soils are also called *regur* (from the Telugu word Reguda) and black *cotton soils* because cotton is the most important crop grown on these soils. Several theories have been put forward regarding the origin of this group of soils but most pedologists believe that these soils have been formed due to the solidifaction of lava spread over large areas during volcanic activity in the Deccan Plateau, thousands of years ago. Most of the black soils are derived from two types of rocks, the Deccan and the Rajmahal trap and ferruginous gneisses and schists occurring in Tamil Nadu. The former are sufficiently deep while the later are generally shallow.

Krebs holds that the regur is essentially a mature soil which has been produced by relief and climate, rather than by a particular type of rock.

According to him, this soil occurs where the annual rainfall is between 50 to 80 cm. and the number of rainy days are from 30 to 50. The occurrence of this soil in the West Deccan where the rainfall is about 100 cm. and the number of rainy days more than 50, is considered by him to be an exception.

In some parts of Gujarat and Tamil Nadu, the origin of black cotton soils is ascribed to old lagoons in which the rivers deposited the materials brought down from the interior of Peninsula covered with lava.

Geographically, black soils are spread over 5.46 lakh sq. km. (*i.e.* 16.6 per cent of the total geographical area of the country) encompassed between 15°N to 25°N latitudes and 72°E to 82°E longitudes. This is the region of high temperature and low rainfall. It is, therefore, a soil group of the dry and hot regions of the Peninsula. These soils are mainly found in Maharashtra, western Madhya Pradesh, parts of Karnataka, Andhra Pradesh, Gujarat and Tamil Nadu.

The black colour of these soils has been attributed by some scientists to the presence of a small proportion of titaniferous magnetite or even to iron and black constitutents of the parent rock. The black colour of this soil may even be derived from crystalline schists and basic gneisses such as in Tamil Nadu and parts of Andhra Pradesh. Various tints of the black colour such as deep black, medium black, shallow black or even a mixture of red and black may be found in this group of soils (See Fig. 4.1).

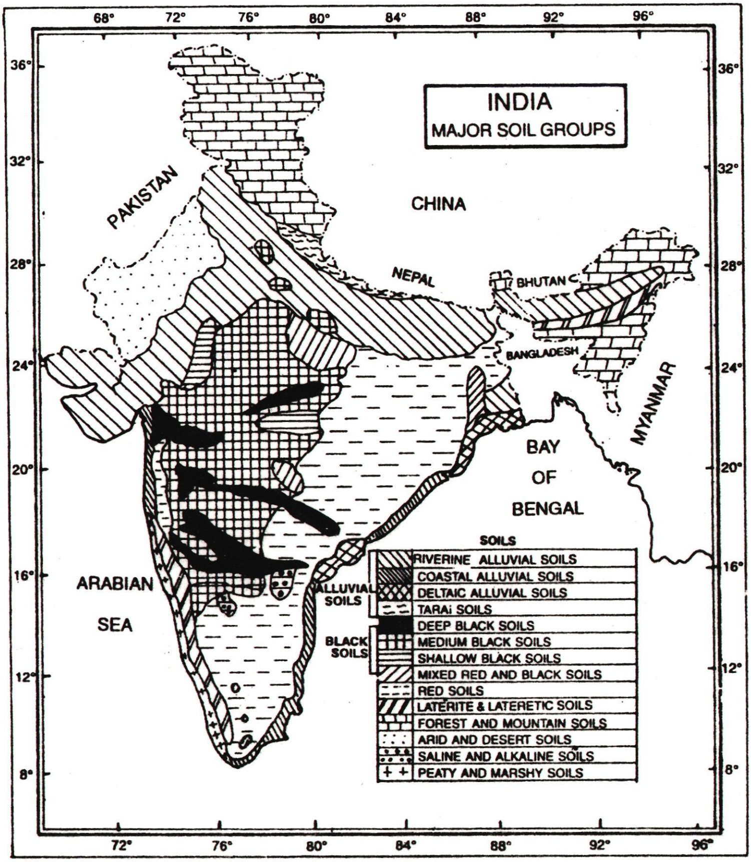
INDIA
MAJOR SOIL GROUPS
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
MYANMAR
BAY OF BENGAL
ARABIAN SEA
SOILS
ALLUVIAL SOILS
BLACK SOILS
RIVERINE ALLUVIAL SOILS
COASTAL ALLUVIAL SOILS
DELTAIC ALLUVIAL SOILS
TARAI SOILS
DEEP BLACK SOILS
MEDIUM BLACK SOILS
SHALLOW BLACK SOILS
MIXED RED AND BLACK SOILS
RED SOILS
LATERITE & LATERETIC SOILS
FOREST AND MOUNTAIN SOILS
ARID AND DESERT SOILS
SALINE AND ALKALINE SOILS
PEATY AND MARSHY SOILS
68° 72° 76° 80° 84° 88° 92° 96°
36° 32° 28° 24° 20° 16° 12° 8°

Fig. 4.1 : Major Soil Groups of India.

The black soil is very retentive of moisture. It swells greatly and becomes sticky when wet in rainy season. Under such conditions, it is almost impossible to work on such foil because the plough gets stuck in the mud. However, in the hot dry season, the moisture evaporates, the soil shrinks and is seamed with broad and deep cracks., often 10 to 15 cm wide and upto a metre deep. This permits oxygenation of the soil to sufficient depths and the soil has extraordinary fertility. This soil has been used for growing a variety of crops for centuries without adding fertilizers and manures, or even following with little or no evidence of exhaustion.

A typical black soil is highly argillaceous with a large clay factor, 62 per cent or more,. without gravel or coarse sand. It also contains 10 per cent of alumina, 9-10 per cent of iron oxide and 6-8 percent of lime and magnesium carbonates. Potash is variable (less than 0.5 per cent) and phosphates, nitrogen and humus are low.

The structure is cloddish but occasionally friable. In all *regur* soils in general, and in those derived from ferromagnesian schists in particular, there is a layer rich in *kankar* nodules formed by segregation of calcium carbonate at lower depths. As a general rule, black soils of uplands are of low fertility but they are darker, deeper and richer in the valleys.

Because of their high fertility and retentivity of moisture, the black soils are widely used for producing several important crops. Some of the major crops grown on the black soils are cotton, wheat, jowar, linseed, Virginia tobacco, castor, sunflower and millets. Rice and sugarcane are equally important where irrigation facilities are available. Large varieties of vegetables and fruits are also successfully grown on the black soils.

3. Red Soils

This comprehensive term designates the largest soil group of India, comprising several minor types. Most of the red soils have come into existence due to weathering of ancient crystalline and metamorphic rocks. The main parent rocks are acid granites and gneisses, quartzitic and felspathic. The colour of these soils is generally red, often grading into brown, chocolate, yellow, grey or even black. The red colour is due more to the wide diffusion rather than to high percentage of iron content.

The red soils occupy a vast area of about 3.5 lakh sq. km. which is about 10.6 per cent of the total geographical area of the country. These soils are spread on almost the whole of Tamil Nadu, parts of Karnataka, south-east of Maharashtra, eastern parts of Andhra Pradesh, Madhya Pradesh, Orissa and Chota Nagpur. In the north the red soil area extends in large parts of the Santhal Parganas in Bihar; the Birbhum and Bankura districts of West Bengal; Mirzapur, Jhansi, Banda and Hamirpur districts of Uttar Pradesh; Aravallis and the eastern half of Rajasthan, parts of Assam, Nagaland, Manipur, Mizoram, Tripura and Meghalaya.

By and large, the red soils are poor in lime, magnesia, phosphates, nitrogen and humus, but are fairly rich in potash. In their chemical composition they are mainly siliceous and aluminous, with free quartz as sand, the alkali content is fair, some parts being quite rich in potassium. The texture of these soils varies from sand to clay, the majority being loams. On the uplands, the red soils are thin, poor and gravelly, sandy or stoney and porous, but in the lower areas they are rich, deep dark and fertile.

The red soils respond well to the proper use of fertilizers and irrigation and give excellent yields of cotton, wheat, rice, pulses, millets, tobacco, oil seeds, potatoes and fruits.

4. Laterite and Lateritic Soils

The word 'laterite' (from Latin letter meaning brick) was first applied by Buchanan in 1810 to a clayey rock, hardening on exposure, observed in Malabar. But many authors agree with Fermor's restriction of this term to soils formed as to 90-100 per cent of iron, aluminium, titanium and manganese oxides. According to majority opinion, the laterite soil is formed under conditions of high temperature and heavy rainfall with alternate wet and dry periods.

According to Polynov laterite soils may be "the end products of weathering given sufficiently long time". In the opinion of George Kuriyan, "It is probably the end product of decomposition found in regions of heavy rainfall, more than 200 cm." Such climatic conditions promote leaching of soil whereby lime and silica are leached away and a soil rich in oxides of iron and aluminium compounds is left behind. We have numerous varieties of laterite which have bauxite at one end and an indefinite mixture of ferric oxides at the other.

Almost all laterite soils are very poor in lime and magnesia and deficient in nitrogen. Sometimes, the phosphate content may be high, probably present in the form of iron phosphate but potash is deficient. At some places, there may be higher content of humus.

The laterite and lateritic soils are widely spread in India and cover an area of 2.48 lakh sq. km. They are mainly found on the summits of Western Ghats at 1000 to 1500 m. above mean sea level, Eastern Ghats, the Rajamahal Hills, Vindhyas, Satpuras and Malwa Plateau. They also occur at lower levels and in valleys in several other parts of the country. They are well developed in south Maharashtra, parts of Karnataka, Andhra Pradesh, Orissa, West Bengal, Kerala, Bihar, Assam and Meghalaya.

Due to intensive leaching and low base exchange capacity, typical laterite soils generally lack fertility and are of little use for crop production. But when manured and irrigated, some laterites and lateritics are suitable for growing plantation crops like tea, coffee, rubber, cinchona, coconut, arecanut, etc. In low lying areas paddy is also grown. Some of the laterite soils in Kerala, Karnataka, Chota Nagpur region of Bihar, Orissa and Assam respond well to the application fertilizers like nitrogen, phosphorus and potassium. In some areas, these soils support grazing grounds and scrub forests.

Laterite and lateritic soils have a unique distinction of providing valuable building material. These soils can be easily cut with a spade but hardens like iron when exposed to air. Because it is the end-product of weathering, it cannot be weathered much further and is indefinitely durable.

5. Forest and Mountain Soils

Such soils are mainly found on the hill slopes covered by forests. These soils occupy about 2.85 lakh sq. km. which is about 8.67 per cent of the total land area of India. The formation of these soils is mainly governed by the characteristic deposition of organic matter derived from forest growth. These soils are heterogeneous in nature and their character changes with parent rocks, ground- configuration and climate. Consequently, they differ greatly even if they occur in close proximity to one another. In the Himalayan region, such soils are mainly found in valley basins, depressions, and less steeply inclined slopes. Generally, it is the north facing slopes which support soil cover; the southern slopes being too precipitous and exposed to denudation to be covered with soil. Apart from the Himalayan region, the forest soils occur on Western and Eastern Ghats as well as in some parts of the Peninsular plateau.

The forest soils are very rich in *humus* but are deficient in potash, phosphorus and lime. Therefore, they require good deal of fertilizers for high yields. They are especially suitable for plantations of tea, coffee, spices and tropical fruits in Karnataka, Tamil Nadu and Kerala and wheat, maize, barley and temperate fruits in Jammu and Kashmir and Himachal Pradesh.

6. Arid and Desert Soils

A large pan of the arid and semi-arid region in Rajasthan and adjoining areas of Punjab and Haryana lying between the Indus and the Aravalis, covering an area of 1.42 lakh sq. km. (or 4.32% of total area) and receiving less than 50 cm of annual rainfall, is affected by desert conditions. The Rann of Kuchchh in Gujarat is an extension of this desert. This area is covered by a mantle of sand which inhibits soil growth. This sand has originated from the mechanical disintegration of the ground rocks or is blown form the Indus basin and the coast by the prevailing south-west monsoon winds. Barren sandy soils without clay factor are also common in coastal regions of Orissa, Tamil Nadu and Kerala. The desert soils consist of aeolian sand (90 to 95 per cent) and clay (5 to 10 per cent). Some of these soils contain high percentages of soluble salts, are alkaline with varying degree of calcium carbonate and are poor in organic matter. Over large parts, the calcium content increases downwards and in certain areas the subsoil has ten times calcium as compared to that of the top soil. The phosphate content of these soils is as high as in normal alluvial soils. Nitrogen is originally low but its deficiency is made up to some extent by the availability of nitrogen in the form of nitrates. Thus, the presence of phosphates and nitrates make them fertile soils wherever moisture is available. There is, therefore, great possibility of reclaiming these soils if proper irrigation facilities are available. The changes in the cropping pattern in the Indira Gandhi Canal Command Area is a living example of the utility of the desert soils. However, in large areas of desert soils, only the drought resistant and salt tolerant crops such as barley, rape, cotton, wheat, millets, maize and pulses are grown. Consequently, these soils support a low density of population.

7. Saline and Alkaline Soils

In the drier parts of Bihar, Uttar Pradesh, Haryana, Punjab, Rajasthan and Maharashtra, there are salt- impregnated or alkaline soils occupying 68,000 sq. km. of area. These soils are liable to saline and alkaline efflorescences and are known by different names such as *reh, kallar, usar, thur, rakar, karl and chopan.* There are many undercomposed rock and mineral fragments which on weathering liberate sodium, magnesium and calcium salts and sulphurous acid. Some of the salts are transported in solution by the rivers, which percolate in the sub-soils of the plains. In canal irrigated areas and in areas of high sub-soil water table, the injurious salts are transferred from below to the top soil by the capillary action as a result of evaporation in dry season. The accumulation of these salts makes the soil infertile and renders it unfit for agriculture. It has been estimated that about 1.25 million hectares of land in Uttar Pradesh and 1.21 million hectares in Punjab has been affected by *usar*. In Gujarat, the area round the Gulf of Khambhat is affected by the sea tides carrying salt-laden deposits. Vast areas comprising the estuaries of the Narmada, the Tapi, the Mahi and the Sabarmati have thus become infertile.

8. Peaty and Marshy Soils

Peaty soils originate in humid regions as a result of accumulation of large amounts of organic matter in the soils. They contain considerable amount of soluble salts and 10-40 per cent of organic matter. This soil is found in Kottayam and Alappuzha districts of Kerala where it is called *kari*. Marshy soils with a high proportion of vegetable matter also occur in the coastal areas of Orissa and Tamil Nadu, Sunderbans of West Bengal, in Central and northern Bihar and Almora district of Uttar Pradesh. The peaty soils are black, heavy and highly acidic. They are deficient in potash and phosphate. Most of the peaty soils are under water during the rainy season but as soon the rains cease, they are put under paddy cultivation.

SOIL EROSION

Soil erosion is the removal of soil by the forces of nature, particularly wind and water, more rapidly than the various soil forming process can replace it. Soil erosion is a serious menace which is adversely effecting our agricultural productivity and the economy of the country as a whole. Although, the process of soil erosion is imperceptibly slow and it can scarcely be detected, the less over periods of time is indeed very great.

TYPES OF SOIL EROSION

Two natural agents *i.e.*, water and wind, are constantly at work indulging in soil erosion. Therefore, we can talk of two types of soil erosion viz., water erosion and wind erosion.

Water Erosion

During heavy rains, water removes a lot of fertile soil. Rain drops fall with an approximate speed of 10 metres per second and wash away the top soil. The soils most readily detached by raindrop splash erosion are sands and silt. Coarser particles are not shifted about as much because of their greater volume and weight. Run off water is responsible for much soil erosion, moving the soil particles by *surface creep*, saltation and suspension. Water erosion consisting of *rilling, gullying sheet-wash and rain peeling process* is mainly confined to the mountains, hills 'and upper slopes of the piedmont zone. If erosion continues unchecked for a sufficient time, numerous finger-shaped grooves may develop all over the area due to silt laden run off. The whole pattern resembles that of the twigs, branches and trunk of a tree. This is called *rill erosion*. With further erosion of the soil, the rills may deepen and become enlarged and are ultimately turned into gullies. The cutting of soil goes to immense size and volume and the entire area may be turned into *badland topography*. When a gully bed cuts into the soil with an immediate drop of 3 or 4 metres and gradually flattens out, a ravine is formed. The depth of a ravine may extend to 30 metres or even more. When the entire top sheet of soil is carried away by water or by wind, leaving behind barrent rock, it is called *sheet erosion*. This type of erosion is more prominent on relatively steeper slopes, receiving heavy rainfall. Sheet erosion is particularly harmful because it attacks the top soil relatively early and renders the land almost unfit for cultivation.

It is not the total annual rainfall that is important, but rather how and when it comes. A single heavy downpour continuing for a few hours may result in severe soil erosion, while the same amount of rainfall fairly distributed over a longer period may cause little erosion or even may be useful for protecting soil. The slope of the land is a potent factor in determining the velocity of water and the consequent soil erosion. Other things being equal, the steeper the slope the more rapidly does water run down resulting in more soil erosion. Theoretically, *if the rate of flow is doubled, the scouring capacity is increased four times, the carrying capacity thirty two times and the size of the particles carried sixty four times.*

In the coastal areas, tidal waves dash along the coast and cause heavy damage to soil. This is called *sea erosion*. Several coastal areas in Gujarat, Maharashtra, Kerala, Tamil Nadu, Andhra Pradesh and Orissa have suffered heavily at the hands of sea erosion. In the higher reaches of the Himalayan region, soil erosion on a large scale is done by glaciers. This is called *glacial erosion.*

Wind Erosion

In arid and semi arid lands with little rainfall, the wind acts as a powerful agent of soil erosion causing heavy loss to agricultural land. Winds blowing at considerable speed, remove the fertile, arable loose soils leaving behind a depression devoid of top soil.

Wind erosion is accentuated when the soil is dry, weakly aggregated, devoid of vegetation cover along with over grazing and the winds are strong. Even modest wind velocities can keep individual particles of humus, clay and silt in suspension. Very fine, fine and medium sands are moved by wind in a succession of bounds and leaps known as *saltation.* Coarse sand is not usually airborne but rather is rolled along the soil surface. This type of erosion is called surface creep. Very coarse sand (1.0-2.0 mm in diameter), gravels, peds and clods are too large to be rolled by wind, so wind-eroded soils have surfaces covered with coarse fragments larger than 1.00 m.m. in diameter. This kind of arid soil surface is known as *desert pavement.* The coarser, acolian sand thus carried by wind, is deposited on the adjoining fertile lands whose fertility dwindles and sometimes the fertile land merges with the advancing desert. The Thar Desert is advancing at an alarming rate of about 0.5 km. per year.

HUMAN FACTORS OF SOIL EROSION

Soil erosion is the result of a number of factors, working in isolation or in association with one another. Apart from the natural factors such as torrential rainfall, resulting in swift flow of water, strong winds in dry areas, nature of soil and the physiography, man is an important factor responsible for soil erosion. Man's ill gudged activities such as deforestation, overgrazing and faulty methods of agriculture have made soil erosion a serious national problem. Besides diversion of natural drainage courses, wrong orientation of roads and railway, embankments and bridges have also led to soil erosion. Thus, it is rightly said that soil erosion is essentially a problem created by man and also faced by man himself.

1. Deforestation

With the increase in population, the pressure on forest resources is increasing with each passing day. This has resulted in reckless cutting of forests which has led to the problem of soil erosion. Roots of trees and plants bind the soil particles and regulate the flow of water, thus saving soil from erosion. Therefore, deforestation invariably results in floods and soil erosion. The large scale damage to soil in Shiwalik range, the Chos of Panjab, parts of Haryana and the *ravines* of Madhya Pradesh, Uttar Pradesh and Rajasthan is largely due to deforestation.

2. Overgrazing

Forests and grasslands provide much needed fodder for animals. During the rainy season, there is plenty of growth and animals get enough fodder.. But during the long dry period, there is shortage of fodder and the grass is grazed to the ground and torn out by the roots by animals. This leads to loose structure of the soil and the soil is easily washed away by rains. Moreover, soil is pulverised by the hoofs and teeth of animals, especially by sheep and goats and thus proves detrimental to top soil when heavy showers fall on it. Soil erosion due to overgrazing is a common site in the hilly areas of Himachal Pradesh, Jammu and Kashmir and in the dry areas of Rajasthan, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh.

3. Faulty Methods of Agriculture

Much of the soil erosion in India is caused by faulty methods of agriculture. The most outstanding are wrong ploughing, lack of crop rotation and practice of shifting agriculture. If the fields are ploughed along the slope, there is no obstruction to the flow of water and the water washes away the top soil easily. In some parts of the country, the same crop is grown year after year which spoils the chemical balance of the soil. This soil is exhausted and is easily eroded by wind or water.

Another outstanding example of faulty method of agriculture is the *shifting cultivation* practised on vast areas in the north-eastern states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Mizoram as well as in Orissa. It is sporadically practised in Andhra Pradesh, Madhya Pradesh, Maharashtra, Kerala, Karnataka and Tamil Nadu. In this method, a piece of forest land is cleared by felling and burning and crops are grown. The removal of the forest cover leads to the exposure of the soil to rains and sun which results in heavy loss of top soil, especially on the hill slopes. Thus the soil becomes unfit for cultivation and the tribes move to another piece of land after 2-3 years, returning to the earlier one after a gap of 10-15 years. In this way, the whole of the forest area is adversely affected by shifting cultivation resulting in intensive soil erosion in vast areas.

EXTENT OF SOIL EROSION

It has been estimated that an area of over 80 million hectares or about one-fourth of our total area is exposed to wind and water erosion out of which 40 million hectares of land has undergone serious erosion. Ironically the-extent of soil erosion is increasing inspite of our efforts to check soil erosion. Experts have estimated that about 40,000 hectares of our soil is permanently lost to cultivation and much larger area is rendered less productive every year due to wind and water erosion. About 21 million hectares are subject to severe wind erosion in Rajasthan and adjoining areas of Punjab, Haryana, and Gujarat. According to the estimates made by the Indian Council of Agriculture Research (ICAR) the loss due to water erosion is 53.34 million tonnes annually. A working group set up by the Ministry of Home Affairs in 1971 estimated that there are 39.75 lakh hectare ravines spread in 18 states, out of which 27.65 lakh hectares (or 69.55 per cent) are in the states of Madhya Pradesh, Rajasthan, Uttar Pradesh and Gujarat (Fig. 7.2). The aerial survey carried out for Chambal Development Scheme has shown that the area covered by ravines upto 4.5-6.0 metre depth is about 50,600 hectares. In Madhya Pradesh about 4 to 8 lakh hectares are effected by deep gullies and ravines along the banks of rivers Chambal and Kali Sindh. Out of this about 2.4 lakh hectares are in the districts of Gwalior, Morena and Bhind. In Uttar Pradesh the ravines are mostly along the banks of the Chambal, the Yamuna, the Gomti and their tributaries.

The loss of soil due to shifting agriculture is no less pronounced. It has been estimated that more than 15 lakh hectares of forest land is cleared for shifting agriculture every year. The total area affected by shifting cultivation is estimated to be 30-40 lakh hectares. Some portion of this land is permanently lost to agriculture.

About 6.8 million hectares of land are saline and alkaline. There is immediate need to treat these soils to be of some use of agriculture.

ACHIEVEMENTS IN SOIL CONSERVATION

Soil and water conservation measures have been adopted as one of the essential inputs for increasing agricultural output in the country right from the beginning of the First Five Year Plan. Appreciating the value of soil and the seriousness of soil erosion, the Central Government as well State Governments have taken a number of steps to conserve soil. The soil and water conservation division set up by Central Government in the Department of Agriculture and Cooperation aims at providing an overall perspective of problems like water and wind erosion, degradation through water logging, salinity, ravines, torrents, shifting cultivation and coastal sands.

Another scheme was sponsored by the central Government in the Third Plan which aimed at preventing premature siltation of multi-purpose reservoirs. This scheme is presently being implemented in 27 catchments covering 17 states including the Damodar Valley Corporation Area. Soil and water conservation programme is being implemented in critically degraded watersheds having areas between 2,000 to 4,000 hectares. These are being delineated by All India Soil and Land Use Survey Organisation. Till the end of 1997-98 an area of 3.08 million hectares out of the total treatable area of 20.76 million hectares in the catchments of River Valley Projects had been treated.

The *trio* of salinity-alkalinity-acidity leads to deficiency in chemical-biological nutrients and their problem has been acquiring increasing importance. Reclamation of saline and alkaline soils is a difficult task. Removal of the top soil, providing proper drainage to the water logged areas, avoiding seepage of water from canals, installing tube-wells in canal irrigated areas, and afforestation are some of the measures which can check the growth of unwanted salts in these soils. Application of form yard manures, green manures, and addition of gypsum, lime, and sulphur can add to the fertility of these soils. Cultivation of salt-resistant crops like rice, borseem, barley, jowar and sugarcane has been suggested in such soils. A centrally sponsored scheme for reclamation of alkali (usar) soils initiated in the seventh Five Year Plan is continuing in Haryana, Punjab and Uttar Pradesh. The scheme has been extended to Gujarat, M.P. and Rajasthan. Since the inception of the scheme, an area of 4.25 lakh hectares has been reclaimed upto 1997-98.

Land reclamation in the ravines spreading over 27.65 lakh hectares in Madhya Pradesh, Rajasthan, Uttar Pradesh and Gujarat is a challenging job. A ravine reclamation programme was launched in 1987-88 which was transferred to state sector in 1991-92 as per decision of the National Development Council.

Major components of the ravine reclamation programme are peripheral bunding to halt any ingress of ravines, table land treatment in vicinity of upstream of the peripheral bund, afforestation, irrigation of shallow ravines and rehabilitation. About 1.266 lakh hectares of land has been treated so far.

Contour bunding and levelling have been very effective in checking soil erosion and in increasing crop yields. In Maharashtra, Karnataka, Andhra Pradesh, Gujarat and Punjab, an increase of 25 per cent in the crop yields has been recorded as a result of contour bunding. This has also increased the water recharging capacity of wells in the adjoining areas. According to the reports of National Commission on Agriculture, the 'Kharif and 'Rabi' crops raised in semi arid alluvial plains of Uttar Pradesh have recorded yield increases of 35 per cent due to bunding and 60 per cent due to levelling. By bench terracing in the Kunda catchement, Nilgiris (Tamil Nadu) potato yields have gone up by 15-65 per cent.

A scheme for controlling shifting agriculture was implemented in Arunachal Pradesh and Mizoram in 1986-87. A larger scheme was launched in 1987-88 to cover nine states of Arunachal Pradesh, Assam, Meghalaya, Manipur, Tripura, Nagaland, Mizoram, Orissa and Andhra Pradesh. Till 1990-91, 26,532 families were selected for rehabilitation. The scheme involves different activities such as land development, irrigation, agriculture, horticulture, cottage industries, fisheries, social and fuel wood-forestry and minimum housing programmes. By 1991-92 nearly 84.58 lakh hectares were covered under detailed soil survey, 150.75 lakh hectares under priority delineation surveys and 44.41 lakh hectares under reconnaissance survey in different states.

All India Soil and Land Survey Organisation is using remote sensing technology to keep itself abreast with the latest trends.

SOIL CONSERVATION

Soil conservation includes all those measures which help in protecting the soil from erosion and exhaustion. Soil erosion has been continuing over such a large part of India for such a long time that it has assumed alarming proportion. According to Prof. S.P. Chatterjee, "Soil erosion is the greatest single evil to Indian agriculture and animal husbandry".

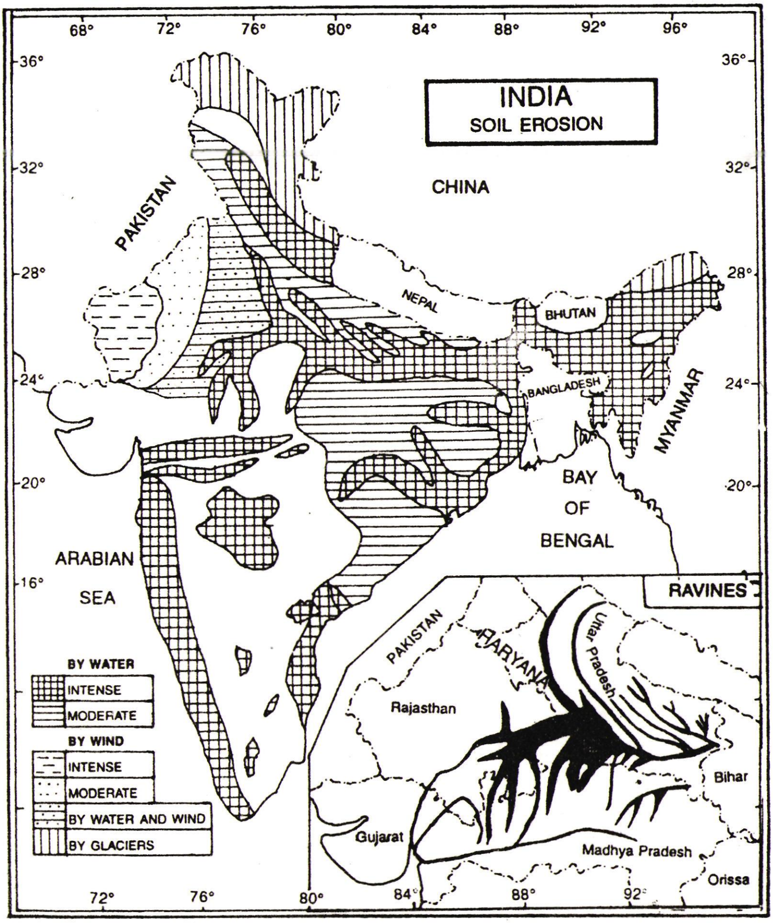
INDIA
SOIL EROSION
68°
72°
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
20°
16°
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
MYANMAR
BAY OF BENGAL
ARABIAN SEA
BY WATER
INTENSE
MODERATE
BY WIND
INTENSE
MODERATE
BY WATER AND WIND
BY GLACIERS
RAVINES
PAKISTAN
HARYANA
Uttar Pradesh
Rajasthan
Bihar
Gujarat
Madhya Pradesh
Orissa

Fig. 7.2 : India Soil Erosion (Inset Ravines).

Soil is our most precious asset and no other gift of nature is so essential to human life as soil. Productive soil alone ensures prosperous agriculture, industrial development, economic betterment and a higher standard of living. A healthy agriculture is bound up with healthy soil. While empassing the significance of conservation, G.T. Renner has said that conservation is defined as "the greatest good to the largest number for the longest time." According to S.I. Kayastha, "*With soil conservation people rise and with its destruction they fall.*" It has been estimated that about two thirds of our arable land needs conservation measures. There is, therefore, an urgent need to conserve soil for the sake of prosperity of our masses. Unfortunately, it has not attracted the attention that it deserves. Our peasantry is not fully aware of many benefits of soil conservation and *neglect of soil is like killing the hen that lays* the golden eggs. Following methods are normally adopted for conserving soil.

1. Afforestation

The best way to conserve soil is to increase area under forests. Indiscriminate felling of trees should be stopped and efforts should be made to plant trees in new areas. A minimum area of forest land for the whole country that is considered healthy for soil and water conservation is between 20 to 25 per cent but it was raised to 33 per cent in the second five year plan; the proportion being 20 per cent for the plains and 60 per cent for hilly and mountainous regions.

2. Checking Overgrazing

Overgrazing of forests and grass lands by animals, especially by goats and sheep, should be properly checked. Separate grazing grounds should be earmarked and fodder crops should be grown in larger quantity. Animals freely move about in the fields for grazing and spoil the soil by their hoofs which leads to soil erosion. This should be avoided.

3. Constructing Dams

Much of the soil erosion by river floods can be avoided by constructing dams across the rivers. This checks the speed of water and saves soil from erosion.

4. Changing Agricultural Practices

We can save lot of our valuable soil by bringing about certain changes in our agricultural practices. Some of the outstanding changes suggested in this context are as under:

(1) Terracing and contour bunding across the hill slopes is a very effective and one of the oldest methods of soil conservation. Hill slope is cut into a number of terraces having horizontal top and steep slopes on the back and front. Contour bunding involves the construction of banks along the contours. Terracing and contour binding which divides the hill slope into numerous small slopes, checks the flow of water, promotes absorption of water by soil and saves soil from erosion. But there is a limit to which bunding is an effective measure of soil conservation. When the slope is steeper than 8 per cent or 1 in 12, bunding becomes expensive and less effective. Nothing over 20 per cent or 1 in 5 should be terraced. Fields of a slope steeper than 15 per cent or 1 in 6 should be withdrawn from ploughing as they are not usually worth the labour of making benches very close together.

(2) Similarly, contour ploughing *i.e.* ploughing the land along the contours or across the slope of the land can help a lot in checking the flow of water and help in avoiding soil erosion.

(3) Ploughing the land in a direction perpendicular to wind direction also reduces wind velocity and protects the top soil from erosion.

(4) Adopting rotation of crops and strip cropping system. In many parts of India, a particular crop is sown in the same field year after year. This practice takes away certain elements from the soil, making it infertile and exhausted rendering it unsuitable for that crop. Rotation of crops is the system in which a different crop is cultivated on a piece of land each year. This helps to conserve soil fertility as different crops make different demands on the soil. For example, wheat may be cultivated in the first year, barley in the second and legumes in the third. The cycle may then be repeated. Further, there are some crops such as maize, cotton, tobacco an Ayotato which can be classed as erosion inducing, whilst some other crops such as grass, forage crops and many legumes are erosion resisting. Small grain crops like wheat, barley, oats and rice are between

these two extremes. Rotation and alteration of erosion-inducing crops with erosion resisting crops, known as *strip cropping* will minimise the problem of soil erosion.

(5) Checking and reducing shifting agriculture by persuading the tribal people to switch over to settled agriculture. This can be done by making arrangements for their resettlement which involves the provision of residential accommodation, agricultural implements, seeds, manures, cattle and reclaimed land.

(6) Use of early maturing varieties reduce soil erosion.

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5

RELIEF AND GEOLOGY

INTRODUCTION

The present landform features of India have evolved over millions of years. These are the outcome of the actions of the Internal movements below the earth's crust and external forces operating on the earth. In earlier class, you have read about the structure of the earth. As you know, the earth's crust is floating on semi-molten rocks of asthenosphere. Radioactive decay in the Interior of the earth produces heat, which escapes towards surface producing convection currents in the molten rocks (Fig. 5.1).

Rising currents tear the crust apart, dividing it into large fragments, called *tectonic* or *lithospheric plates*. There are seven major tectonic plates, namely the Pacific, the North American, the South American, the Eurasian, the African, the Indo-Australian, and the Antarctic plates. While these plates are moving away from each other (diverging) in some places, they are being pushed together (converging) elsewhere. When two plates come together, they may either collide and crumble, or one may slide under the other. At times, they may also move horizontally past over one another.

South of the Himalayas, a basin or depression was formed. It was gradually filled with the alluvium brought by the rivers from north and south. North Indian plain was thus born between the Himalayas and the Peninsular plateau, When the Himalayas were being formed, two major events affected the plateau. An extensive volcanic eruption took place in the north-western part of the plateau. Besides, the western part of the plateau subsided. The Indian Ocean advanced to occupy this depression and thus the Arabian Sea was formed. Because of this subsidence, the Western Ghats became prominent.

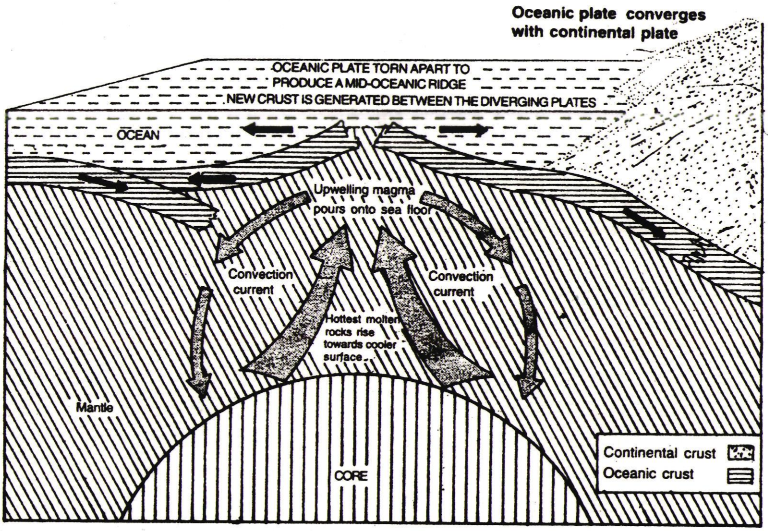
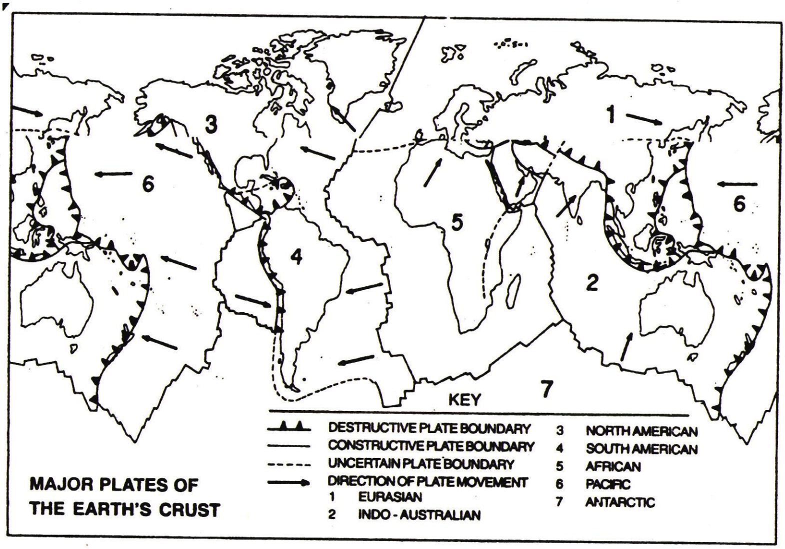

Oceanic plate converges with continental plate
OCEANIC PLATE TORN APART TO PRODUCE A MID-OCEANIC RIDGE
NEW CRUST IS GENERATED BETWEEN THE DIVERGING PLATES
OCEAN
Upwelling magma pours onto sea floor
Convection current
Convection current
Hottest molten rocks rise towards cooler surface
Mantle
CORE
Continental crust
Oceanic crust

Fig. 5.1 : Convection currents in the mantle.


1
2
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6
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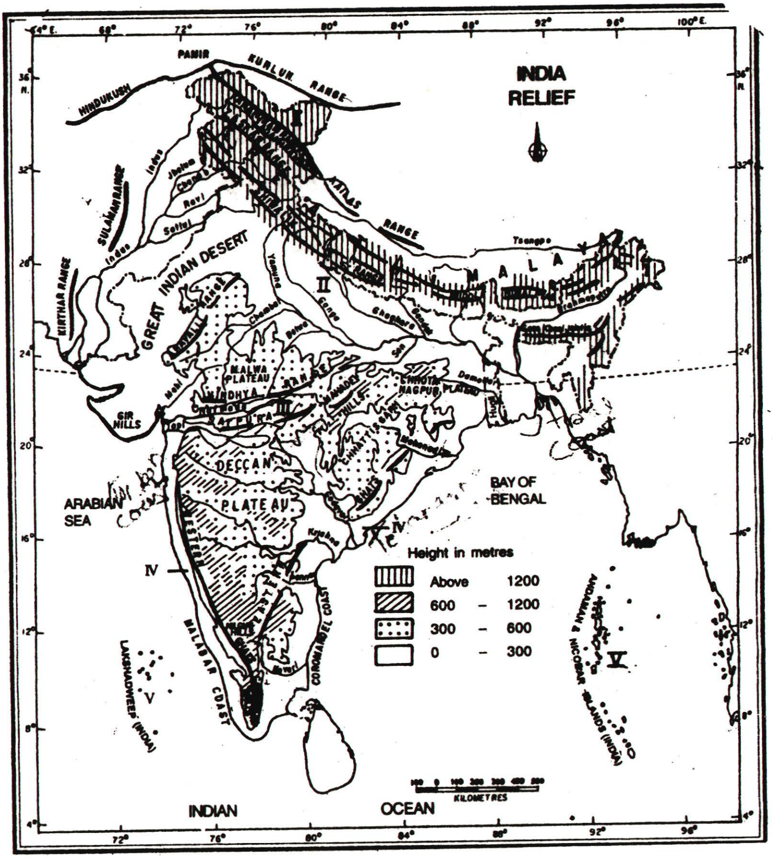
KEY
DESTRUCTIVE PLATE BOUNDARY
CONSTRUCTIVE PLATE BOUNDARY
UNCERTAIN PLATE BOUNDARY
DIRECTION OF PLATE MOVEMENT
1 EURASIAN
2 INDO-AUSTRALIAN
3 NORTH AMERICAN
4 SOUTH AMERICAN
5 AFRICAN
6 PACIFIC
7 ANTARCTIC
MAJOR PLATES OF THE EARTH'S CRUST

Fig. 5.2 : Major plates of the earth's crust.

The land of India is characterised by a great diversity in its reliefer physical features. In the north, there is a vast expanse of rugged terrain made of sedimentary and metamorphic rocks. Series of mountain chains with lofty peaks, enclosed plateaus, and narrow and deep valleys are the characteristic features of this part.


INDIA
RELIEF
64° E.
68°
72°
76°
80°
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96°
100° E.
36° N.
32°
28°
24°
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16°
12°
8°
4°
PAMIR
KUNLUN RANGE
HINDUKUSH
SULAIMAN RANGE
KIRTHAR RANGE
Indus
Jhelum
Chenab
Ravi
Satluj
GREAT INDIAN DESERT
ARAVALLI
Yamuna
Ganga
Chambal
Betwa
Son
Ghaghara
Gandak
Tsangpo
Brahmaputra
HIMALAYA
KAILAS RANGE
II
MALWA PLATEAU
VINDHYA
SATPURA
III
Narmada
Tapi
Mahi
GIR HILLS
CHHOTA NAGPUR PLATEAU
MAIKAL HILLS
Damodar
Hugli
Mahanadi
DECCAN PLATEAU
WESTERN GHATS
EASTERN GHATS
Godavari
Krishna
Kaveri
NILGIRI
IV
V
MALABAR COAST
CORONMANDEL COAST
ARABIAN SEA
BAY OF BENGAL
INDIAN OCEAN
LAKSHADWEEP (INDIA)
ANDAMAN & NICOBAR ISLANDS (INDIA)
Height in metres
▥ Above 1200
▨ 600 - 1200
⁙ 300 - 600
☐ 0 - 300
KILOMETRES

"Based upon Survey of India map, with the permission of Surveyor General of India." The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line. Responsibility for correctness of Internal details shown on the map rests with the publisher. Government of India copyright. 2002.

Fig. 5.3 India Relief.

In contrast, the North Indian plain, drained by the Indus, the Ganga, and the Brahmaputra, is made up of the alluvium. It Is an area of low relief and level or featureless surface. In south, the peninsular plateau is made of igneous and metamorphic rocks, which contain valuable minerals. It is the oldest landmass of the country. It has remnants of the old mountain ranges and dissected plateaus. In some areas, the plateau rises in the form of a staircase. It is bordered by coastal plains to its east and west.

Major Physiographic Divisions

The diverse land features (relief) of India may be grouped as follows (Fig. 5.3):

(i) The Great Mountains of the North;

(ii) The North Indian Plain;

(iii) The Peninsular Plateau;

(iv) The Coastal Plains; and

(v) The Islands.

The main differences in the relief features of these divisions are due to the differences in their geological history and structure. Rocks vary considerably in their resistance to erosion. While sedimentary rocks are easily eroded, igneous rocks like granite are hard to break.

The Great Mountains of the North

In Central Asia, just north of India, lies the Pamir Knot. From here a number of mountain ranges run in different directions. The Hindu Kush projects to the west, the Tien Shan to the north-east, the Kunlun to the east, and the Karakoram to the south-east. The latter enters Kashmir and runs south-east.

It extends further east and is known as the Kailas range. The Karakoram contains K2, the second highest mountain peak of the world. Find out its height. The Karakoram pass is of great importance in this region of high altitude. The Baltoro and the Siachin are the famous glaciers, *i.e.* slow moving rivers of ice and snow of this area.

The Ladakh and the Zaskar ranges run parallel to the south of the Karakoram. The Indus, rising north of the Kailas crosses many ranges and flows between the Ladakh and the Zaskar ranges from south-east to north-west. After entering Pakistan, it flows south and meets the Arabian sea.

The Himalayas extend from the Indus In the west to the Brahmaputra in the east. Forming a convex arc, it covers a distance of about 2,400 km. Its width varies from 400 km in the west to 150 km in the east. However, the height of the mountains in the eastern half is greater than that in the western half.

The Himalayas are young fold mountains. They include three main series of parallel ranges. In between these ranges, there are valleys and plateaus. The northern most range is referred to as the *Great* or *Inner Himalaya* or the *Himadri*. With an average altitude of 6000 metres, it Contains all the prominent peaks of the Himalayas. Mount Everest (8848 m), located In Nepal is the highest peak in the world. Kanchenjunga or Khangchendzonga (8598 m) is the second highest peak of the Himalayas and lies in Sikkim. Nanga Parbat (8126 m) and Nanda Devi (7817 m) are the other two Important Himalayan peaks in India. Find out the names of the states, where they are located.

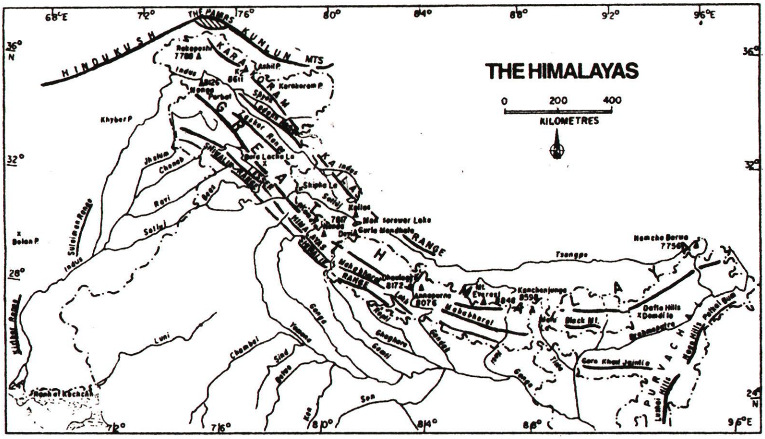

THE HIMALAYAS
0 200 400
KILOMETRES
68°E
72°
76°
80°
84°
88°
92°
96°E
36° N
32°
28°
24 N
THE PAMIRS
HINDUKUSH
KUNLUN MTS
KARAKORAM
Rakaposhi 7788
Ashil P.
K2 8611
Karakoram P.
Indus
8126 Nanga Parbat
Khyber P.
Zaskar Range
GREAT HIMALAYAS
KAILAS
Indus
Shipki La
Satluj
Kailas
Man sarowar Lake
Gurla Mandhata
7817 Nanda Devi
Jhelum
Chenab
Ravi
Beas
Satluj
SHIWALIK RANGE
Bolan P.
Sulaiman Range
Indus
Kirthar Range
Luni
Chambal
Sind
Betwa
Ken
Yamuna
Ganga
Ghaghara
Gomti
Gandak
Son
Mahabharat RANGE
Dhaulagiri 8172
Annapurna 8076
Mahabharat
Mt. Everest 8848
Kanchenjunga 8598
Tsangpo
RANGE
Namcha Barwa 7756
Black Mt.
Dafla Hills
Brahmaputra
Garo Khasi Jaintia
Naga Hills
Patkai Bum
PURVACHAL
Lushai Hills
Tista
Ganga
Rann of Kachchh

Fig. 5.4 : The Himalayas and other mountain ranges of the north.

The *Middle Himalaya* or *Himachal lies to* the south of the Himadri. They extend over an average width of 50 km and have an altitude of 3700 to 4500 metres. The Pir Panjal, the Dhaoladhar and the Mahabharat ranges are a part of this group. All Important hill stations of North India - Dharmashala, Dalhousjie, Shimla, Mussorie and Darjeeling are located on this range.

The *Outer Himalaya* or the *Shiwalik* ranges extend over a width of 10-50 km and have an altitude between 900 and 1100 metres. These are made of unconsolidated, sediments and hence prone to landslides. Large portion of the Shiwaliks at places, are separated from the Middle Himalaya by flat bottomed valleys. These are covered with thick deposits of gravel and alluvium and are called 'duns', *e.g.,* Dehra Dun and Patil Dun.

The Himalayas are divided into four sections in an east-west direction. The western section lying between the Indus and the Satluj, covers large parts of Jammu and Kashmir and a part of Himachal Pradesh. It Is referred to as the Punjab Himalayas. The Pir Panjal range in Jammu and Kashmir has well-known hill resorts of Gulmarg and Pahalgam. The section between the Satluj and the Kali, is known as the Kumaon Himalayas. It lies in Uttaranchal. The section between the Kali and the Tista is known as the Nepal Himalayas and that between the Tista and the Dihang (Tsangpo), as the Assam Himalayas. The later now lies in Arunachal Pradesh.

Some of the important passes of the Himalayas from west to east are Shipkila, Nathula and Bomdila. Find out their locations on the map and name the states where they are located.

The Indus, the Satluj, the Ganga, the Yamuna, the Kosi, the Tista and the Brahmaputra are some of the major rivers of north India. They have their sources In the Himalayas. They are perennial rivers and bring in large volumes of water and sediments with them.

It is Interesting to note that many of them are older than the Himalayas. The Indus, the Satluj and the Tsangpo (Brahmaputra)—originate on the other side of the Himalayas, very close to each other near the Kailas-Mansarovar region.

While the Indus and the Satluj flow westward, the Tsangpo flows east, parallel to the Himalayas. It takes a U-turn around Namcha Barwa (7757 m), where it is known as the Dihang. All the three rivers turn towards the northern plains by crossing the Himalayas at different points, making spectacular gorges. These are I-shaped valleys having steep vertical walls on either side of the river. It Is inferred that rivers continued cutting down their valleys as fast as the Himalayas were rising and thus maintaining a balance between the two opposite actions.

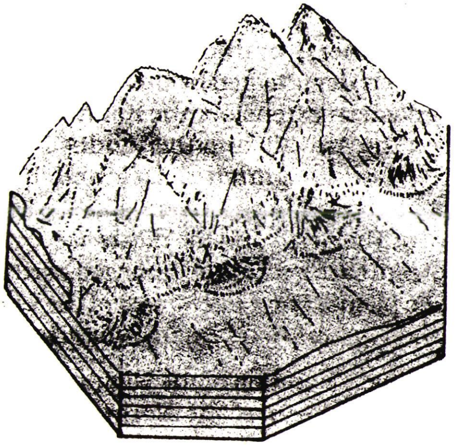
The Himalayas are known for their snow-capped peaks, glaciers, sparkling rivers and beautiful valleys. The valleys of Kashmir, Kullu, and Kangra are world famous for their scenic beauty and fruit orchards belonging to temperate climate.

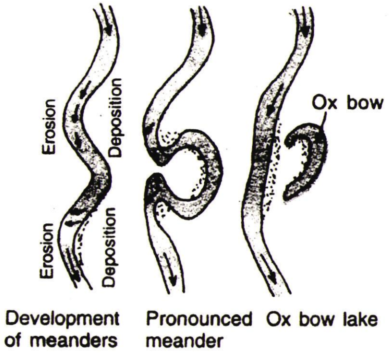
The Dihang (Brahmaputra) marks the eastern most boundary of the Himalayas. The mountain ranges at this point bend sharply to the south and spread along the eastern boundary. They are known as the Purvachal and comprise the Patkal Bum, the Naga hills and the Mizo hills. Moving westward, they run along the Bangladesh-India border in Meghalaya and are known as the Jaintia, the Khasi, and the Garo hills from east to west respectively.

The Northern Plains

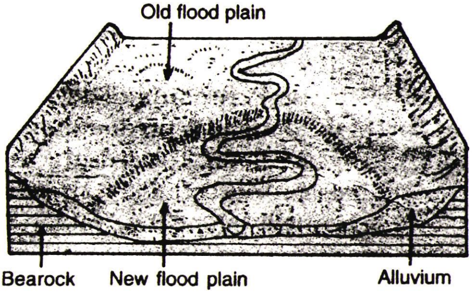
The rivers from the Himalayas in the north and the peninsular plateau in the south have made up this vast plain by depositing alluvium. It is almost a level plain with little variation in relief. A rich soil cover, favourable climate and adequate water supply support agriculture. The river valley civilisations of the Indus and the Ganga flourished in the region as they were based on the cultivation of crops.

When the Himalayan rivers flowing down the slopes of the mountains reach the plains, they form *alluvial fans*. They are triangular-shaped deposits with their base towards the plain. Some other features like flood plains, levees, channel bars and bluffs are the main depositional features formed by the rivers in the plain. In the lower course of the rivers, the slope is gentle. As such they become sluggish. They deposit their load of mud and silt in their channels, which grow into islands.




Erosion
Deposition
Erosion
Deposition
Ox bow
Development of meanders
Pronounced meander
Ox bow lake

b. Meanders and Ox bow lakes


Old flood plain
Bearock
New flood plain
Alluvium

c. Flood plains

Fig. 5.5 : Common riverine features In the plains.

To circumvent these obstructions, rivers go on splitting into channels-called distributaries. While a *tributary* joins the main river by adding waters from its basin, a distributary carries away a part of the water from the main river. The river waters get distributed through these channels, which spread over a very large area. This vast alluvial plain, triangular in shape, is called a *delta*.

The North Indian Plain extends between the mouths of the Indus and the Ganga- Brahmaputra, covering a distance of about 3200 km. Its width varies between 300 and 150 km. It gets narrower towards the east. The Northern Plains are broadly divided into the Indus river system In the west, and the Ganga-Brahmaputra river system in the east.

The Indus and its tributaries—the Jhelum, the Chenab, the Ravi, the Beas and the Satluj originate in the Himalayas. The Indus, flowing westward, makes loops and turns south to meet the Arabian Sea. The land between two rivers Is locally known as the *doab*, (*do* – meaning two and *ab* – meaning water). Hence, the plain made by the five rivers has been named as the Punjab (Panch + *ab*). The larger part of this plain lies in Pakistan.

The Ganga enters the Northern Plains at Haridwar and flows eastward. On its way to the sea, it is joined by a number of tributaries both from north and south. After reaching West Bengal, it turns south. It is joined by the Brahrnaputra in Bangladesh, which enters India in Arunachal Pradesh. Flowing south for a while, the Brahmaputra turns west and crosses Assam. Upon reaching Bangladesh, it turns south again. The joint stream of the Ganga and the Brahmaputra flows by the name of Meghna and drains into the Bay of Bengal. The Ganga-Brahmaputra delta is the world's largest and the fastest growing delta.

On the basis of the differences In the relief, the plain is divided into (i) Bhabar, (ii) Tartar (iii) Bhangar, and (iv) Khadar. A narrow belt covered With pebbles lies along the foot of the Shiwaliks from the Indus to the Tista. They are laid down by numerous streams descending down the hills. The pebbled beds are parallel to the slope of the river bed. This belt is about 8 to 16 km in width and is known as the *bhabar*. Next to the bhabar is the *tarai zone*, which is wet and marshy. It has a thick forest and a variety of wild life. The older alluvium of the plain is called the *bhangar*. With continuous deposition of alluvium, a terrace like feature is formed, which rises above the level of the flood plain. The younger alluvium of the flood plains is known as the khadar.

The Peninsular Plateau

It is the oldest part of the country. This triangular region has its base towards the Northern Plains, between the Delhi Ridge and the Rajmahal Hills. Geologically, the Shillong plateau is an extension of this region. The apex is formed by Kanyakumari in south. The plateau has a general elevation of 600-900 metres. Its northern part slopes towards norths and east, which is reflected through the courses of the rivers—the Chambal, the Son and the Damodar. South of the Satpura-Maikal ranges, the slope is towards the east and the south-east. But the region lying in the north-western part of the Deccan Is drained by rivers flowing west.

The Peninsular block may be subdivided into two parts: the Central Highlands, and the Deccan plateau.

The Central Highlands

The northern part of the Peninsular plateau consists of a number of plateaus, denuded mountain ranges and low hills. This part is made of hard igneous rocks.

The north-western part of the plateau is occupied by the Aravali range, which is a relict of the old fold mountains. Running in southwest-northeast direction from Gujarat to Delhi, they form discontinuous ridges. The Thar Desert lies to the west of this range. It is an arid desert. The vast expanse of sand is dominated by sand dunes of varying sizes.

The southern boundary of the Central Highlands is demarcated by the Vindhya range and its eastern extension, the Kaimur hills. In between the Aravalll and the Vindhya ranges lies the *Malwa plateau*. Drained by the Chambal and the Betwa rivers, it is fairly wide and open. The north and the north-eastern side of the plateau gradually merges with the Gangetic plains. The eastern part of the Central Highlands is known as *Bundelkhand.*

In the middle section of the Highland region, between the valleys of the Narmada and the Son, escarpments are formed by the Vindhyan-Kaimur range. An escarpment refers to a wall-like, steep slope of a ridge, forming a long barrier rising above the surrounding land. East of the Son, the Chhotanagpur plateau in Jharkhand is also part of this region. It consists of horizontally laid lava-sheets. All rivers of the Central Highland region join the Yamuna and the Ganga from south.

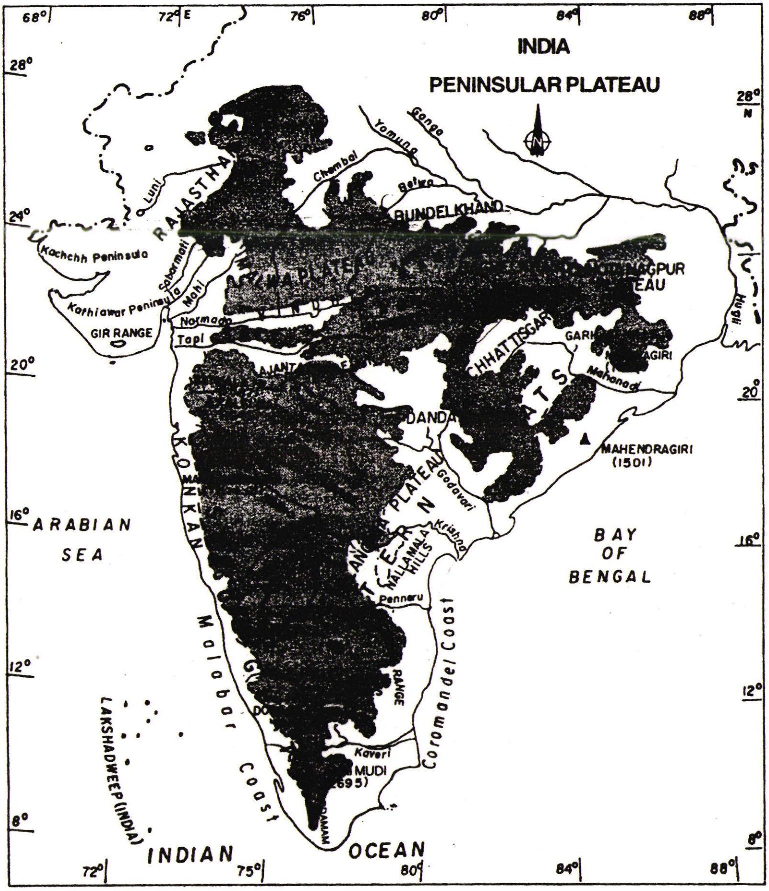
The Rajmahal hills and the Shillong plateau are fragments of the peninsular plateau. It seems that the connecting rock formations have been now buried under the alluvium of the Ganga plains.

The Deccan Plateau

The Deccan plateau extends southward from the Satpura, the Mahadeo and the Maikala ranges to the southern tip of the Peninsula. The north-western part of the plateau is predominantly a region formed by lava flows. Towards the west, the Western Gnats form its boundary, stretching almost uninterruptedly along the Arabian Sea coast. They are known by different local names. It is called the Sahyadri in Maharashtra and Karnataka, the Nilgiri in Tamil Nadu, and the Annamalai and the Cardamom hills along the Kerala-Tamil Nadu border. The southern part of the Western Ghats are relatively higher.

The Coastal Plains

The Peninsular plateau is flanked by plains all along the coast from Gujarat to Orissa. It is divided into the eastern and the western coastal plains. The western coastal plain stretches from Gujarat to Kerala. Except for the Gujarat part, it is generally narrow. They are highly rugged and dissected. In the northern part, it is known as the Konkan coast. South of Goa, it is called the Malabar coast. Unlike the eastern coast, only a few large rivers—the Narmada and the Tapi, flow through it. Rivers of the western coast form estuaries) Most estuaries are drowned valleys resulting from a relative rise of sea-level.


INDIA
PENINSULAR PLATEAU
68°
72° E
76°
80°
84°
88°
28°
24°
20°
16°
12°
8°
Ganga
Yamuna
Chambal
Betwa
Luni
RAJASTHAN
BUNDELKHAND
Kachchh Peninsula
Kathiawar Peninsula
Sabarmati
Mahi
GIR RANGE
Narmada
Tapi
CHOTANAGPUR PLATEAU
Hugli
CHHATTISGARH
GARHJAT
Mahanadi
DANDAKARANYA
MAHENDRAGIRI (1501)
Godavari
Krishna
KONKAN
ARABIAN SEA
BAY OF BENGAL
NALLAMALA HILLS
Penneru
Coromandel Coast
Malabar Coast
RANGE
LAKSHADWEEP (INDIA)
Kaveri
ANAIMUDI (2695)
INDIAN OCEAN
72°
75°
80°
84°
88°

"Based upon Survey of India map, with the permission of Surveyor General of India." The territorial waters of India extend Into the sea to a distance of twelve nautical miles measured from the appropriate base line The boundary shown on this map is as interpreted from the North-Eastern areas (Reorganisation) Act, 1971, but has yet to be verified. Responsibility for correctness of Internal details shown on the map rests with the publisher. Government of India copyright. 2002.

Fig. 5.6 : The Peninsular Plateau.

They make ideal sites for the development of fishing and ports. The western coast has many good natural harbours such as Mumbai and Marmagao. In the far south, the Kerala coast is known for its salt-water lakes, called lagoons. Sand bars and spits are important depositional features of the coastal landforms. The eastern coastal plain is comparably much wider than the western coastal plain. The alluvial deposits are very thick in the delta regions of the rivers Kauveri, Krishna, Godavari and Mahanadi. The coast of southern Andhra Pradesh and Tamil Nadu is popularly known as the Coromandel coast.

The Islands

The Island groups of India— the Lakshadweep, and the Andaman and Nicobar islands are of different origin. The Lakshadweep consists of many small islands. They lie opposite the coast of Kerala in the Arabian Sea. The southern-most Island of this group is very close to the Maldives, our Island neighbour in the south. These islands, formed of coral deposits, are called *atolls*. It Is originally derived from the Malyalam word 'atolu'.

The Andaman and Nicobar islands, on the other hand, are bigger in size. They are more numerous and scattered. They are at a greater distance from the coast of the mainland. They are submerged hill ranges, some of them are of volcanic origin. There are about 200 islands in the Andaman group and 19 islands in the Nicobar group. Only a few of them have a length of 60 to 100 km. These Islands spread over 350 km. These Island groups are of great strategic importance for the country.

A detailed account of the different physiographic units highlights the unique features of each region. It would, however, be clear that each region complements the other and makes the country richer in its natural resources. The northern mountains are the major sources of water and forest wealth. The Northern Plains are the granaries of the country. They provided the base for early civilisations. The plateau is a storehouse of minerals, which has played a crucial role in the industrialisation of the country. The coastal region and island groups provide sites for fishing and port activities. Thus the diverse physical features of the land have immense future possibilities of development.

THE HIMALAYAN MOUNTAINS

The Himalayan mountains are also known as the *Himadri, Himavan* or *Himachal*. The Himalayas consist of the youngest and the loftiest mountain chains in the world. The magnitude of their size can be estimated from the fact that the central axial range of the main Himalayas alone stretches for a distance of over 2400 km. (over 22° longitude) from the Indus gorge in the west to the Brahmaputra gorge in the east.

The width of the Himalayas varies from 500 km. in Kashmir to 200 km. in Arunachal Pradesh. The total area of the Himalayan mountain region is nearly five lakh sq. km. The Pamir, popularly known as the *roof of the world* is the connecting link between the Himalayas and the high ranges of Central Asia. From the Pamir, the Himalayas extend eastward in the form of an arcuate curve which is convex to the south. The southern boundary of the Himalayas is well defined by the foothills (300 m. contour line) but the northern boundary is rather obscure and merges with the edge of the Tibet Plateau.

The Himalayas have attained a unique personality owing to their high altitude, steep gradient, snow capped summits, deeply dissected topography, youthful drainage, complex geological structure and rich temperate flora in the subtropical latitudes.

The Himalayan mountain chains have the lofties peaks of the world. The number of peaks higher than 8000 metre is 14 and those over 7500 metre total 20. Of the 94 Asian peaks which exceed 7300 metre, all but two are in the Himalaya and Karakoram ranges. The number of peaks over 7000 metre runs into hundreds and several peaks above 6000 metre have not been adequately counted and mapped. Many of them have not been even given their names till now.

ORIGIN OF THE HIMALAYAS

Several scholars have expressed their views regarding the origin of the Himalayas. The prominent among them are O.H.K. Spate, D.N. Wadia, M.S. Krishnan, S. Burrard, E.H. Pasco, G.E. Pilgrim, de Terra, T.T. Paterson, T. Hagen, Auden, A. Heim and A. Gansser, Wager and a host of others. There is almost a complete unanimity that the Himalayan mountains have come out of a great geosynchine called the *Tethys Sea* and that the uplift has taken place in different phases. But divergent views have been expressed regarding the process and time of uplift as well as the forces responsible for such a vast scale uplift.

About 120 million years ago, the arrangement of continents and oceans was quite different from what it is today. There used to be a vast shallow sea, known as the Tethys Sea lying between the *Angaraland* in the north and the *Gondwanaland in the south.* Sediments were brought by rivers from these land masses and deposited at the bed of this sea. These sediments were subjected to powerful compression, either because of the southward movement of the Angaraland or due to the northward movement of the Gondwanaland. Majority of the scientists believe that it is the northward movement of the Gondwanaland which caused compression in the sediments at the floor of the Tethys Sea. In any case, whether Angaraland moved southwards or Gondwanaland moved northwards or both moved towards each other, the net result would be the same; the sediment in the *Tethys Sea* was squeezed and crushed, and a series of folds were formed one behind the other giving birth to the highest relief features on the earth—the Himalayas. The curved shape of the Himalayas convex to the south, is attributed to the maximum push offered at two ends of the Indian Peninsula during its northward drift. In the northwest it was done by the Aravalis and in the north-east by the Assam ranges, both acting as two extended arms pushing out the extremities, while the central area sagged giving the arcuate shape to the Himalayas. The recent studies have shown that India is moving northwards at the rate of about five cms. per year and crashing into rest of the Asia, buckling the Himalayas between Angaraland and Gondwanaland.

It is important to note that the Himalayas do not comprise a single range but a series of at least three ranges running more or less parallel to one another. Therefore, the Himalayas are supposed to have emerged out of the *Himalayan Geosyncline i.e.,* the Tethys Sea in three different phases following one after the other. The first phase commenced about 120 million years ago, when the Great Himalayas were formed. Some geologists are of the opinion that the formation of the Great Himalayas was completed about 70 million years ago. The second phase took place about 25 to 30 million years ago when the Middle Himalayas were formed. The Shiwaliks were formed in the last phase of the Himalayan orogeny—say about two million to twenty million years ago (Fig. 5.7).

The diastrophic movements which helped in the formation of the Himalayas started in the late Cretaceous times and continued through the Eocene, Middle Miocene, Pliocene to the lower Pliocene and finally into the upper Pleistocene to sub-Recent times. There are evidences to show that the process of uplift of the Himalayas is not yet complete and they are still rising. The heights of various places as determined by trigonometrical methods indicate that the Himalayas continue to rise till date. According to the estimates made by Godwin Austen, the average elevation of the Himalayas was 2440 m. above the sea level about a million years ago which has now risen to 3050 m. The Mahabharat range is still in a state of rigorous uplift. Some of the fossil formations found in the Shiwalik hills are also available in the Tibet plateau.

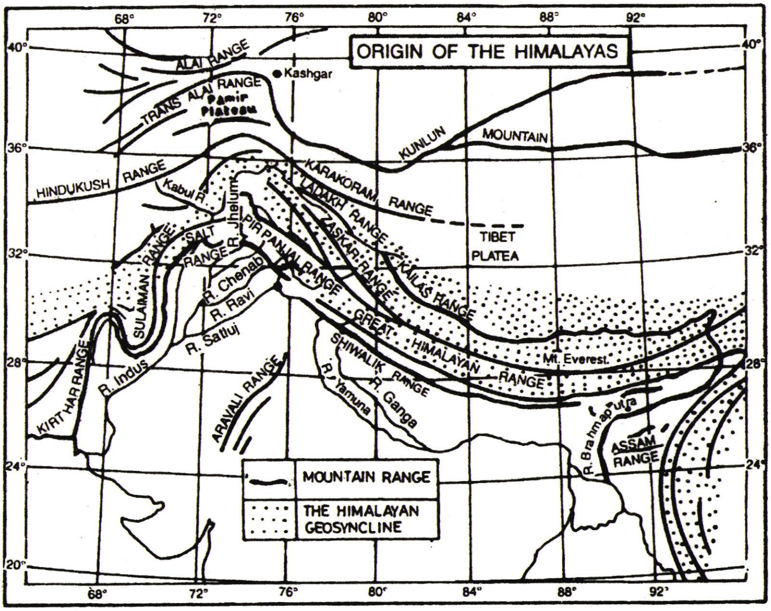

ORIGIN OF THE HIMALAYAS
68°
72°
76°
80°
84°
88°
92°
40°
36°
32°
28°
24°
20°
ALAI RANGE
Kashgar
TRANS ALAI RANGE
Pamir Plateau
KUNLUN MOUNTAIN
HINDUKUSH RANGE
Kabul R.
R. Jhelum
KARAKORAM RANGE
LADAKH RANGE
ZASKAR RANGE
KAILAS RANGE
TIBET PLATEA
SALT RANGE
SULAIMAN RANGE
PIR PANJAL RANGE
R. Chenab
R. Ravi
R. Satluj
GREAT HIMALAYAN RANGE
Mt. Everest
KIRTHAR RANGE
R. Indus
ARAVALLI RANGE
SHIWALIK RANGE
R. Yamuna
R. Ganga
R. Brahmaputra
ASSAM RANGE
MOUNTAIN RANGE
THE HIMALAYAN GEOSYNCLINE

Fig. 5.7 : Origin of the Himalayas.

It indicates that the past climate of the Tibet plateau was somewhat similar to the climate of the Shiwalik hills and that the elevation of Tibet plateau was almost the same as that of the present Shiwalik hills and the plateau has since risen to its present elevation. The desiccation of the lakes of Tibet within recent or even historical times provides proof of the further uplift of the Himalayas. Surrounding these lakes, the sand and gravel terraces at higher levels, sometimes 60-100 metres above the present water level, are seen which prove that the water stood at a much higher level till recent times. This could be possible only in the event of uplift of the region. The frequent occurrence of earthquakes in the Himalayan region shows that the Himalayas have not yet attained the *isostatic equilibrium* and they still continue to rise further. The Himalayan rivers are still in their youthful stage and have been rejuvenated in recent times. This is another proof of rising trend in the Himalayas. The present rate of uplift of the Himalayas has been calculated at 5 to 10 cm. per year.

DIVISION OF THE HIMALAYAS

Geographers generally tend to divide the Himalayas on geographical, regional and geological basis. Geographically the entire Himalayan region can be divided into:

(i) The Himalayan Ranges,

(ii) The Trans-Himalayas, and

(iii) The Eastern Hills.

(i) The Himalayan Ranges

The Himalayas are not a single chain or range of mountains, but a series of several more or less parallel or converging ranges. These ranges are separated by deep valleys. As in all young fold mountains, we find a densely dissected "*ridge-and-valley-topography*" in the Himalayas. The most outstanding valleys in the Himalayan region are the vale of Kashmir and the Karewas, the Kangra and Kulu valley in Himachal Pradesh; the Dun valley; the Bhagirathi valley (near Gangotri) and the Mandakini valley (near Kedarnath) in Uttar Pradesh and the Kathmandu valley in Nepal. The individual ranges have very steep gradient towards the south but they present a much gentler slope towards the north. In the eastern section the Himalayas rise abruptly from the plains of Bengal and Oudh and suddenly attain great elevations within a short distance from the foot of the mountains. Thus the peaks of Kanchenjunga and Everest are only a few kilometres from the plains and are clearly visible from there. In contrast, the western Himalayas rise gradually from the plains through a series of lesser ranges. Their peaks of perpetual snow are 150 to 200 km. away from the plain areas. A succession of at least three parallel ranges from the Indo-Gangetic plain to the Tibet plateau may be recognised in the Himalayas.

(a) The Shiwalik Range

The Shiwalik comprises the outermost range of the Himalayas and is also known as the *Outer Himalayas;* Overlooking the Great Plain, this chain of hills runs almost parallel to the lesser Himalayas for a distance of about 2400 km. from the Potwar Plateau to the Brahmaputra valley. The width of the Shiwaliks varies from 50 km. in Himachal Pradesh to less than 15 km. in Arunachal Pradesh. It is an almost unbroken succession of low hills except for a gap of 80-90 km. which is occupied by the valley of the Tista River. The altitude varies from 600 to 1500 metres. The Shiwaliks are formed of great thickness of Mio-Pleistocene sands, gravels and conglomerates which have been brought by the rivers flowing from the higher range of the Himalayas. It has been folded,, faulted and indurated by the earth movements from the Middle Miocene to the lower Pliestocene ages. Obviously the Shiwaliks were formed last of all the ranges. The Shiwaliks are known by different names in different areas. They are called Jammu Hills in Jammu and Dafia, Miri, Abor and Mishmi Hills in Arunachal Pradesh. The Dhang Range, Dundwa Range and the Churia Ghat Hills of Nepal also form parts of the Shiwalik range.

As the Shiwalik Hills were formed after the formation of the Himalayas, they obstructed the courses of the rivers draining from the higher reaches of the Himalayas and formed temporary lakes. The debris brought by those rivers were deposited in these lakes. After the rivers had cut their course through the Shiwalik Range, the lakes were drained away leaving behind plains called *duns*. Dehra Dun is the best example of such a plain which is 75 km. long and 15-20 km. wide. Kota, Path and Chaukhamba are other duns in Uttar Pradesh. In the Jammu hills the extensive picturesque duns of Udhampur and Kotii are quite typical.

The eastern part of the Shiwalik range upto Nepal is covered with thick forests but the forest cover becomes thin in the west. The southern slopes of this range are almost completely devoid of forest cover in Punjab and Himachal Pradesh and are highly dissected by several seasonal streams locally called *Chos*.

(b) The Middle or the Lesser Himalaya

In between the Shiwaliks in the south and the Great Himalayas in the north is the Middle Himalaya running almost parallel to both the ranges. It is also called the *Himachal* or *Lower Himalaya*. It has an intricate system of ranges which are 60-80 km. wide having elevations varying from 3500 to 4500 m. above sea level. Many peaks are more than 5050 m. above sea level and are snow covered throughout the year. The important ranges included are the Pir Panjal, the Dhaola Dhar, the Mussoorie Range, the Nag Tiba and the Mahabharat Lekh. The Pir Panjal range in Kashmir is the longest and the most important range. It extends from the Jhelum river to the upper Beas river for 300-400 km. and is separated from the Zaskar Range by the valley of Kashmir. It rises to 5,000 metre and more in elevation and contains mostly volcanic rocks. The best known passes of the Pir Panjal range are the Pir Panjal Pass (3480 m.), the Bidil (4270 m.), Golabghar Pass (3812 m.) and Banihal Pass (2835 m.). The Banihal Pass is used by the Jammu-Srinagar highway. The Kishanganga, the Jhelum and the Chenab cut through this range. South-east of the Ravi, the Pir Panjal is continued by the Dhaola Dhar range, passing through Dalhousie, Dharmshafa, and Shimla. This is the southernmost range of the Middle Himalayas and rarely attains elevations higher than 4,000 metre.

Between the Pir Panjal and the Zaskar Range of the main Himalayas, lies the famous valley of Kashmir running over a distance of about 135 km. in a south-east to north- west direction. This valley is about 40 km. broad in its midddle. Its total area is 4921 sq. km. and its average elevation is 1585 m. above mean sea level.

Geographers and geologists have divergent views regarding the origin of this valley. Wadia thinks that the valley of Kashmir is the synclical basin enclosed between the Pir Panjal to the south and an offshoot of the central axial range to the north while de Terra feels that it is a recently depressed interment basin pointing to mark evidence of faulting on the Himalayan Hank. However, it is generally believed that this basin was occupied by a lake in the Pleistocene age.

This was filled with sediment and uplifted to form the Kashmir Valley. The synclinal basin of the valley is floored with a variety of alluvial deposits, lacustrine fluvial and fluvioglacial, through which the Jhelum River meanders majestically before entering the deep gorge it has cut through the Pir Panjal. In Himachal Pradesh there is Kangra Valley. It is a strike valley and extends from the foot of the Dhaola Dhar Range to the south of Beas. On the other hand, the Kulu Valley in the upper course of the Ravi is transverse valley.

Further east, the Middle Himalayas are marked by the Mussoorie and the Nag Tibba ranges. The Mussoorie range has an average elevation of 2000-2600 and runs over a distance of 120 km. from Mussoorie to Lansdowne. Mussoorie, Nainital, Chakrata and Ranikhet are important hill stations situated at 1500 to 2000 metres above sea level.

The Mahabharat Lekh, in southern Nepal is a continuation of the Mussoorie Range. Its summits rise to 3000 m. and its average elevation varies from 1500 to 2000 m. above sea level. The Kathmandu valley to its north is a very important feature of this area. East of the Sun Kosi River, the Sapt Kosi, Sikkim, Bhutan, Miri, Abor and Mishmi hills represent the lower Himalayas.

On the whole, the Middle Himalayan ranges are less hostile and more friendly to human contact. Majority of the Himalayan hill resorts like Shimla, Mussoorie, Ranikhet, Nainital, Almora and Darjeeling, etc. are located here.

(c) The Great Himalaya

This is also known as *Inner Himalaya, Central Himalaya or Himadri*. This is the northernmost or the innermost of all the Himalayan ranges. With an average elevation of 6100 m. above sea level and an average width of about 25 km., this is the loftiest and the most continuous mountain range of the world. It is about 150 km. away from the northern edge of the plains of Northern India. It is mainly formed of the central crystallines (granites and gneisses) overlain by metamorphosed sediments. The folds in this range are asymetrical with steep south slope and gentle north slope. The asymmetrical development of the two slopes is much more pronounced in the east of Satluj, where excess of precipitation on the southern slope is much greater than in the west of the river. This mountain arc, convex to the south, terminates abruptly in the Nanga Parbat in north-west and in the Namcha Barva in the north-east.

This mountain range boasts of the tallest peaks of the world, most of which remain under perpetual snow. There are several peaks over 8000 m. in altitude. They are, in descending order of altitude, mount Everest, also called *Sagarmatha* or *Chomo Langma* (8848 m.), *Everest South Peak* (8754 m.), Kanchenjunga I (8598 m.), Lhotse I (8501 m.), m. akalu (8481 m.), Kanchenjunga South Peak (8474 m.), Kanchenjunga West Peak (8420 m.), Lhotse Intermediate Peak (8410 m.), Lhotse Shar (8384 m.), Dhaulagiri (8172 m.), manasulu (8156 m.), Cho Oyu (8153 m.), Nanga Parbat (8126 m.) Annapurana (8078 m.), Gosainthan or Shisha Pangma (8013 m.), makalu South Peak (8010 m.). The number of known peaks rising over 7000 m. in elevation exceeds forty. Some of the important peaks between 7000 and 8000 m. elevation are Nanda Devi (7817 m.), Karnet (1156 m.), Namcha Barwa (7756 m.), Guria mandhata (7728m.), Badri Nath (7138 m.), Trisul (7138 m.).

This range is so formidable that it cannot be easily crossed even through the passes because they are generally higher than 4570 m. above sea level and are snowbound for most of the year. The Burzil Pass and the Zoji La in Jammu and Kashmir, the Bara Lacha La and the Shipki La in Himachal Pradesh, the Thaga La, the Niti Pass and the Lipu Lekh pass in Uttar Pradesh and the Nathu La and the Jelep La in Sikkim are the important passes through the great Himalaya. The Hindustan-Tibet Road connecting Shimla with Gartok in Western Tibet passes through the Shipki La. Another important trade route connecting Kalimnong (near Darjeeling) with Lhasa in Tibet, however passes through Jelep La (4386 m).

(ii) The Trans Himalayas

The Himalayan ranges immediately north of the Great Himalayan range are called the trans-Himalayas. This part of the Himalayan ranges is also called the *Tibetan Himalaya* because most of it lies in Tibet. The Zaskar, the Ladakh, the Kailas and the Karakoram are the main ranges of the Trans-Himalayan system. It stretches for a distance of about 1000 km. in east-west direction and its average elevation is 3000 m. above mean sea level. The average width of this region is 40 km. at the eastern and western extremities and about 225 km. in the central part.

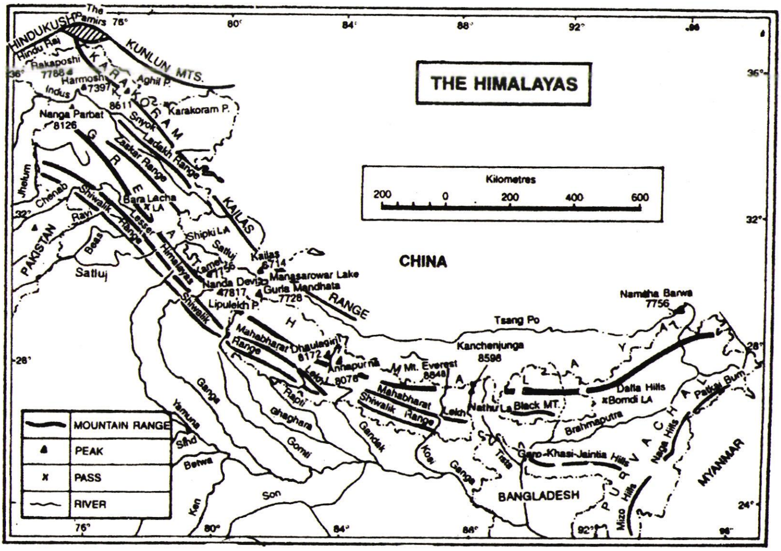
The *Zaskar Range* branches off from the great Himalayan Range near 80°'E longitude and runs more or less parallel to it. The Nanga Parbat (8126 m) forms its culmination in the north-west but the adjoining Deosai Mountain may also be included in it. North of the Zaskar Range and running parallel to it is the Ladakh Range. It is about 300 km. long and its average elevation is 5800 metre above the sea level. Only a few peaks of this range attain heights of over 6000 metres. The Rakaposhi. Haramosh Ranges beyond the Indus may be treated as the extension of the Ladakh Range to the northwest. The Kailas Range (*Gangdise in Chinese*) in western Tibet is an offshoot of the Ladakh range. Its average elevation is 5,500-6,000 m. above sea level and its average width is 30 km. The highest peak is Mount Kailas (6714 m). River Indus originates from the northern slopes of the Kailas range. The northern most range of the Trans Himalayan Ranges in India is the Great Karakoram Range. It forms India's frontier with Afghanistan and China and acts as the watershed between India and Turkistan. It extends eastwards from the Pamir for about 800 km. The average width of this range is 120-140 km. It is a range of lofty peaks and its elevation hardly ever falls below 5500 m. It is the abode of some of the greatest glaciers of the world outside the polar regions. Some of the peaks are more than 8000 metre above sea level. K^2 (8611 m) is the second highest peak in the world and the highest peak in the Indian Union (excluding the auxiliary peaks of the Great Himalayas) and rises majestically like a cone. It has been named as *Godwin Austen* by the Britishers and *Qogir* by the Chinese. The other peaks located in its neighbourhood and rising more than 8000 m. above sea level are the Gasherbrum I or Hidden Peak (8068 m.), Broad Peak (8047 m.) and Gasherbrum II (8035 m.). Another 19 peaks in Korakoran cross the 7600 m. elevation and those over 7,000 m. have not yet been fully enumerated.

The Ladakh Plateau lies to the north-east of the Karakoram Range. With an average elevation of over five thousand metre above sea level, it is the highest plateau of the Indian Union. It has been dissected into a number of plains and mountains, the most outstanding among them being Soda Plains, Aksai Chin, Lingzi Tang, Depsang Plains and Chang Chenmo.

(iii) The Eastern Hills or The Purvachal

After crossing the Dihang gorge, the Himalayas take a sudden southward turn and form a series comparatively low hills running in the shape of a crescent with its convex side pointing towards the west. These hills are collectively called the *Purvachal* because they are located in the eastern part of India. Extending from Arunachal Pradesh in the north to Mizoram in the south, they form India's boundary with Myanmar. Differing markedly from the Himalaya in the scale of their relief and in their morphology, these hill ranges none the less stem from the same orogeny.

In the north is the Patkai Bum which forms the international boundary between Arunachal Pradesh and Myanmar. It is made up of strong sandstone and rises to an elevation varying from 2000 m. to 3000 m. After running for some distance southwards, it merges into Naga Hills where Saramati (3826m) is the highest peak. Patkai Bum and Naga Hills form the watershed between India and Myanmar. The Kohima hills to west are made up of sandstone and slate and have a very rough topography. South of Naga Hills are the Manipur hills which are generally less than 2500 metres in elevation. They form boundary between Manipur and Myanmar. The Brail range separates Naga Hills from Manipur Hills.


THE HIMALAYAS
HINDUKUSH
The Pamirs
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
Hindu Raj
Rakaposhi 7788
Harmosh 7397
Indus
K 8611
KUNLUN MTS.
Aghil P.
KARAKORAM
Karakoram P.
Nanga Parbat 8126
Snyok
Ladakh Range
Zaskar Range
GREAT
Jhelum
Chenab
Shiwalik
Bara Lacha LA
Ravi
PAKISTAN
Beas
Satluj
Range
Lesser
Himalayas
Shipki LA
Satluj
KAILAS
Kailas 6714
Kamet 7756
Manasarowar Lake
Nanda Devi 7817
Gurla Mandhata 7728
RANGE
Lipulekh P.
Shiwalik
H
Mahabharat Range
Dhaulagiri 8172
Annapurna 8078
Mt. Everest 8848
CHINA
Kilometres
200 0 200 400 600
Tsang Po
Namcha Barwa 7756
Kanchenjunga 8598
A
L
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A
Mahabharat
Shiwalik Range
Leikh
Nathu La
Black MT.
Dafla Hills
Bomdi LA
Brahmaputra
Patkai Bum
PURVACHAL
Naga Hills
Garo-Khasi-Jaintia Hills
Mizo Hills
MYANMAR
BANGLADESH
Ganga
Yamuna
Rapti
Ghaghara
Gomti
Gandak
Kosi
Ganga
Tista
Sind
Betwa
Ken
Son
MOUNTAIN RANGE
PEAK
PASS
RIVER

Fig. 5.8 : The Himalayas.

Further south the Brail Range swings to south-west and then west into Jaintia, Khasi and Garo hills which are eastward continuation of the Indian peninsular block and has been separated by the Bengal Basin. South of the Manipur Hills are the Mizo Hills which have an elevation of less than 1500 metres. The highest point is the Blue Mountain (2157 m) in the south. It is abovious that the elevation of the eastern hills decreases as we move from north to south. Although, comparatively low, these hill ranges are rather forbidding because of the rough terrain, dense forests and swift streams.

REGIONAL DIVISION OF THE HIMALAYAS

Sir Sidney Burrard divided the entire length of the Himalayas into following four divisions on the basis of the river valleys:

The Punjab Himalayas

The 560 km. long stretch of the Himalayas between the Indus and the Satluj rivers is known as the Punjab Himalayas. A large portion of this sector lies in Jamrnu and Kashmir and Himachal Pradesh as a result of which it is also called the Kashmir and Himachal Himalaya. Korakoram, Ladakh, Pir Panjal, Zashar and Dhaula Dhar are the main ranges of this section. The 3444 metre high Zoji La pass provides easy passage. In between the main ranges, there are valleys, duns, and lakes. The general elevation falls westwards.

The Kumaon Himalayas

Between the Satluj and the Kali rivers is the 320 km. long Kumaon Himalaya. Its western part is called Garhwal Himalaya while the eastern part is known as Kumaon Himalaya proper. The general elevation is higher as compared to Panjab Himalayas. Nanda Devi (7817 m.), Kamet (7756 m.), Trisul (7138 m.), Badrinath (7138 m.), Kedarnath (6945 m.), Gangotri (6510 m.) are important peaks. The sources of sacred rivers like the Ganga and the Yamuna are located in the Kumaon Himalayas. There are several duns between the Middle Himalayas and the Shiwalik Hills. Nainital and Bhimtal are important lakes.

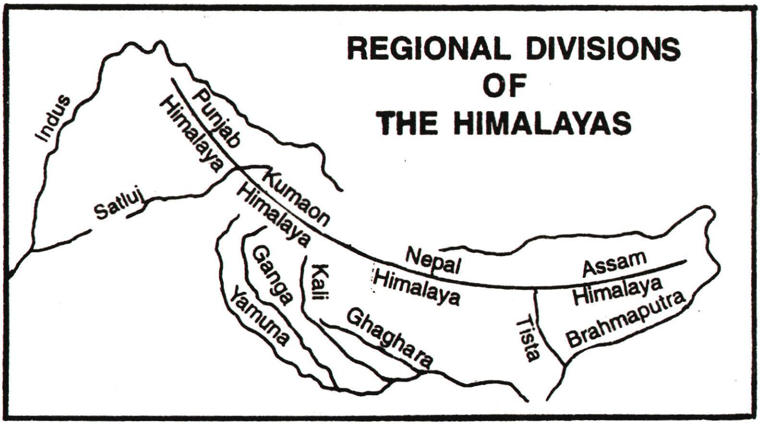
REGIONAL DIVISIONS
OF
THE HIMALAYAS
Indus
Punjab
Himalaya
Satluj
Kumaon
Himalaya
Ganga
Yamuna
Kali
Ghaghara
Nepal
Himalaya
Tista
Assam
Himalaya
Brahmaputra

Fig. 5.9 : Regional Divisions of the Himalayas.

The Nepal Himalaya

This section of the Himalayas stretches for a distance of 800 km. between the Kali and the Tista rivers. Most of it lies in Nepal as a result of which it is called the *Nepal Himalayas*. This is the tallest section of the Himalayas and is crowned by several peaks of perpetual snow. The Mount Everest (8848 m.), named after Sir George Everest the then Surveyor General of India, is the tallest peak of the world. The other major peaks are Kanchenjunga (8598 m.), Lhotse I (8501 m.), Makalu (8481 m.), Dhaula Giri (8172 m.), Cho Oyu (8153 m.) and Annapurna (8078 m.). Kathmandu is a famous valley in this region.

The Assam Himalayas

The Himalayan ranges from Tista to Brahamputra rivers covering a distance of 750 km. are called the Assam Himalayas. This part of the Himalayas spreads over large parts of Sikkim, Assam and Arunachal Pradesh and has elevation much less than that of the Nepal Himalayas. The southern slopes are very steep but the steepness decreases towards the west. The lesser Himalayas are very narrow and are very close to the great Himalayas. The important peaks of this region are Namcha Barwa (7756 m.), Kula Kangri (7539 m.) and Chomo Lhari (7327 m.),

THE SYNTAXIAL BENDS OF THE HIMALAYAS

The general east-west trend of the Himalayas terminates suddenly at its western and eastern extremities and the ranges are sharply bent southward in deep knee-bend flextures which are called *syntaxial bends*. The western syntaxial bend is near Nanga Parbat where the Indus has cut a deep gorge. This bend is about 480 m. deep and affects all ranges starting from the Pamir upto the foothills. The geological formations here take a sharp hair-pin bend as if they were bent round pivotal point obstructing them.

There is a similar hair pin bend in Arunachal Pradesh where the mountains take a sharp bend from the eastern to southern direction after crossing the Brahmaputra river. The tectonic strike also undergoes a deep knee-bend from an easterly to southerly trend. The geological character of the rocks also changes.

GLACIERS OF THE HIMALAYAS

As the name implies, the Himalayas are the *abode of snow* and are called the *storehouse of snow*. Out of a total area of five lakh square kilometre of the Himalayas, about 33,000 sq. km. area is covered by snow. Evidences of large snow areas in the past are available in abundance. The active glaciers and the associated landscape provide an ideal platform for investigation of historic glacial variation. Obviously the Pleistocene ice was far more extensive than that of today. There are about 15,000 glaciers in the Himalayas lying between the two syntaxial bends in the east and west. The *snow line, the lowest level of perpetual snow*, varies to a great extent in different parts of the Himalayas depending upon latitude, amount of precipitation and local topography. While the glaciers of Kanchenjunga in Sikkim portion hardly move below 3965 m., and those of Kumaon and Lahul to 3660 m. the glaciers of the Kahsmir Himalayas may descend to 2,500 m. above sea level. T.D. La Touche while elaborating the cause of these variations, has suggested that in part it is due to the increase in latitude from 28° N in the Kanchenjanga to 36° N in the Karakoram, and in part because of the fact that the eastern Himalayas rise abruptly from the plains without the intervention of high ranges. Though the total precipitation is much less in the western Himalayas it all takes place in the form of snow. In the Great Himalayan ranges, the snow line is at lower elevation on the southern slopes than on the northern slopes because the southern slopes are steeper and receive more rainfall as compared to the northern slopes.

The maximum development of glaciers occurs in the Karakoram range. This range accounts for about 16,000 sq. km. or about half of the snow bound area of the Himalayan region. Some of the largest glaciers outside the polar and sub-polar regions are found on this range. The southern side of this range nourishes a number of gigantic glaciers, some of which are exceeded in size by the great Humboldt of Greenland only. The 75 km. long *Siachan Glacier* in Nurba valley has the distinction of being the largest glacier outside the polar and the sub-polar regions. Lolofond and Teram Shehr are its main tributaries. The second largest is the 74 km. long *Fedchenko Glacier*. It covers an area of 450 sq. km. in the north-western Pamir and has a depth of nearly 550 m. of ice. Third comes the *Hispar Glacier*. It is 62 km. long and occupies a tributary of the Hunza River. It combines with 59 km. long *Biafo Glacier* occupying about 65 sq. km. area of Braldoh valley. Kunyong or Lak (24 km.) is an important tributary of the *Hisper Glacier*. The west flowing *Baltoro Glacier* also flows in the Braldoh valley. The depth of solid ice at the end of the Baltoro Glacier is about 120 m.; this thickness in the middle of the glacier could be much greater. The great *Godwin Austen Glacier* drains three sides of K^2 and joins the Baltoro Glacier. The *Punmah Glacier* also flows in the Braldoh valley. This 27 km. long glacier has a complex system of branches in its upper reaches. The Batura Glacier draining the Hunza is also 58 km. long and is considered to be the fifth longest glacier, along with Baltoro, outside the sub-polar region. The sixth largest glacier outside the sub-polar region is the 50 km. long *Chogo Lungma* glacier in the Rakaposhi Range. It terminates at an altitude of 2075 m., the lowest recorded in the Himalayas. The other two glaciers draining into the Hunza Valley are the Pasu (25 km.) and Sasaini or Ghulkin (18 km.). The 47 km. long *Khurdopla Glacier* in the Shingshal valley is fed by the snow lake which supplies the *Biafo Glacier*. The Rimo Glacier occupying the Shyok valley is about 40 km. long. It is joined by the 20 km. long Yarkand Rimo from the north. The other Glaciers in the Shyok valley are the *Chong Kumdan* (21 km.) Kichik Kumdan (11 km.) and Aktash (8 km.). The *Khurdopla Glacier* in Shingshal valley is 47 km. long. The other glaciers of this valley are the *Virjerab Glacier* (40 km.), the *Mombil Yaz* (32 km.), *Yazghil* (31 km.) and the *Malangutti Yaz* (23 km.) The *Gasherbrum* and the *Kyagar* in the Shaksgam valley are 21 km. long each. The *Urdok Glacier* lying below these two glaciers is nearly 23 km. long.

The glaciers of the Pir Panjal Range are less numerous and smaller in size as compared to those of the Karakoram Range. The longest *Sonapani Glacier* in the Chandra Valley of Lahul and Spiti region is only 15 km. long. Rising at about 4000 m.

near the Rohtang Pass and flowing in south west direction it has developed a dry lake basin about 2.5 km. long as 1.5 km wide, just below the ice cliff. The *Bara Shigri Glacier* also occupies the Chandra Valley. The rough estimates put its length varying from 10 to 20 km. The largest glacier in the Nun Kun massif is the *Gangri Glacier* which is 13 km. long. The glaciers of the Nanga Parbat massif are small in size and are moving fast due to steep slope. The *Chungphar, Rakhiot, Buzhi* and *Tashan* are important glaciers.

In the Kumaon-Garhwal region of the Himalayas, the largest is the 30 km. long *Gangotri Glacier* which is the source of the holy Ganga. It is fed by five tributary glaciers, the largest of which is 24 km. long. The second largest glacier of this region is the *Milam Glacier* which occupies the valley of the Gori Ganga River. It is 20 km. long and is formed by the union of nine tributary glaciers. The other glaciers of this region are the *Mana Glacier* (18 km.), the *Bhagirath-Kharak* (18 km.), the *Satopanch* (16 km.) the *Sankalpa Glacier* (12 km. and the *Raikane Glacier* (9 km.).

In the central and eastern Himalayas, there is *Rongbuk Glacier* on the northern side of the Mount Everest. This is 52 km. long and is considered to be the largest outside the Karakoram. Another important glacier of the Everest group is the *Khumbu Glacier*, (20 km.) lying in the south of the Everest. The 25 km. long *Zemu Glacier* flows in the easterly direction at the head of the Zemu River. It is about one kilometre wide with 180 metre thick ice. The 21 km. long *Kanchenjunga Glacier* descends from the peak of the same name and occupies the head of Kangchen river. Both the Zemu and the Kanchenjanga glaciers are formed as a result of the union of several branches coming down from the peaks. The *Yalung Glacier* is 16 km. long and flows in a south-west direction from the Kanchenjunga peak. The *Tailing Glacier* (13 km.) also flow-southwest wards. This glacier is separated from the *Alukthang Glacier* by a ridge. Though, only 5 km. long the *Alukthang glacier* is unique because it is clearly visible from Darjeeling at the foot of the Kanchenjunga m clear weather. The *Knagshung Glacier* is 19km. long and flows east of the Everest. The *Barun Glacier* flowing down the Baruntse peak is about 15 km. long.

THE SIGNIFICANCE OF THE HIMALAYAS

The Himalayas comprise the most dominating geographical feature of India. No other mountain range anywhere in world has affected the life of people and shaped the destiny of a nation as the Himalayas have done in respect of India. *The Himalayas are the body and soul of India.* In a very special measure, the Himalayas constitute India's national mountain system. The following few points will bring out the significance of the Himalayan mountains to India.

Source of Rivers

Almost all the great rivers of India have their sources in the Himalayan ranges. Abundant rainfall and vast snow-fields as well as large glaciers are the feeding grounds of the mighty rivers of India. Snow melt in summer provides water to these rivers even during dry season and these are perennial rivers. The Himalayan rivers, along with hundreds of their tributaries, form the very basis of life in the whole of north India.

Fertile Soil

The great rivers and their tributaries carry enormous quantities of alluvium while descending from the Himalayas. This is deposited in the Great Plain of North India in the form of fertile soil, making the plain one of the most fertile lands of the world. It has been estimated that the Ganga and the Indus carry 9 and 10 lakh tonnes of silt, per day respectively and the silt carried by the Brahmaputra is even more. It is, therefore, often said that the *great plain of north India is the Gift of the Himalayas.*

Hydroelectricity

The Himalayan region offers several sites which can be used for producing hydroelectricity. There are natural waterfalls at certain places while dams can be constructed across rivers at some other places. The vast power potential of the Himalayan rivers still awaits proper exploitation.

Tourism

By virtue of their scenic beauty and healthy environment, the Himalayan ranges have developed, a large number of tourist spots. The hilly areas in the Himalayas offer cool and comfortable climate when the neighbouring plains are reeling under the scorching heat of the summer season. Millions of tourists from different parts of the country as well as from abroad throng the Himalayan tourist centres to enjoy their natural beauty and to escape from the summer heat of the plains. The increasing popularity of winter sports and the craze to enjoy the snowfall has increased the rush of tourists in winters also. Srinagar, Dalhousie, Dharamshala, Chamba, Shimla, Kulu, Manali, Mussoorie, Nainital, Ranikhet, Almora, Darjeeling, Mirik. Gangtok, etc. are important tourist centres in the Himalayas.

Climatic Influence

The Himalayas play a very significant role in influencing the climate of India. By virtue of their high altitude, length and direction, they effectively intercept the summer monsoons coming from the Bay of Bengal and Arabian Sea and cause precipitation in the form of rain or snow. Besides, they prevent the cold continental air masses of central Asia from entering into India. Had there been no Himalayas, the whole of India would have been a desert in the absence of precipitation and its winters would have been very severe under the influence of cold air coming from Central Asia.

Defence

The Himalayas have been protecting India from outside invaders since the early times thus serving as a defence barrier. But the Chinese aggression on India in October, 1962 has reduced the defence significance of the Himalayas to a considerable extent. In spite of advancement in modern defence technology, the defence significance of the Himalayas cannot be ignored altogether.

Pilgrimage

Apart from places of tourists interest, the Himalayas are proud of being studded with sanctified shrines which are considered to be the abodes of the Gods. Large number of pilgrims track through difficult terrain to pay their reverence to these sacred shrines. Kailas, Amarnath, Badrinath, Kedarnath, Vaishno devi, Jwalaji, Uttarkashi, Gangotri, Yamunotri, etc. are important places of pilgrimage.

Minerals

The Himalayan region contains many valuable minerals. There are vast potentialities of mineral oil in the tertiary rocks. Coal is found in Kashmir. Copper, lead, zinc, nickel, cobalt, antimony, tungsten, gold, silver, limestone, semi-precious and precious stones, gypsum and mangnesite are known to occur at more than 100 localities in the Himalayas, Unfortunately, many of the mineral resources cannot be exploited at the present level of technological advancement due to adverse geographical conditions. Further advancements in modern technology may help in exploiting these resources. So the future possibilities of mineral exploitation in the Himalayas are great.

Forest Wealth

The Himalayan ranges are very rich in forest resources. In their altitude, the Himalayan ranges show a succession of vegetal cover from the tropical to the Alpine. The Himalayan forests provide fuel wood and a large variety of raw materials for forest based industries. Besides many medicinal plants grow in the Himalayan region. Several patches are covered with grass offering rich pastures for grazing the animals.

Agriculture

The Himalayas do not offer extensive flat lands for agriculture but some of the slopes are terraced for cultivation. Rice is the main crop on the terraced slopes. The other crops are wheat, maize, potatoes, tobacco and ginger. Tea is a unique crop which can be grown on the hill slopes only. A wide variety of fruits such as apples, pears, grapes, mulberry, walnut, cherries, peaches, apricot, etc. are also grown in the Himalayan region.

THE GREAT PLAIN OF NORTH INDIA

To the south of the Himalayas and to the north of the Peninsula lies the Great Plain of North India. It is an aggradational plain formed by the depositional work of three major river systems viz., the Indus, the Ganga and the Brahmaputra. This arcuate plain is also known as Indo-Gangetic-Brahmaputra Plain. This is the largest alluvial tract of the world extending for a length of 3200 km. from the mouth of the Indus to the mouth of the Ganga, of which the Indian sector alone accounts for 2400 km. in length. Its average width varies from 150 to 300 km. It is widest in the west where it stretches for about 500 km. Its width decreases in the east. It is about 280 km. wide near Allahabad and 160 km. near Rajmahal Hills. It widens to about 460 km. in Bengal but narrows down in Assam where it is only 60-100 km. wide. It covers a total area of 7.8 lakh sq. km. The northern boundary of this plain is well defined by the foothills of the Shiwaliks but its southern boundary is a wavy irregular line along the northern edge of the Paninsular India.

Rivers flowing through this plain, especially those originating in the Himalayas have deposited a thick layer of alluvium throughout the length and breadth of this plain. However, the thickness of the alluvium deposit varies from place to place and different estimates have been made about it. According to Oldham, the maximum depth of the soil is about 5,000 m. near its southern edge. It has probably maximum depth between Delhi and Rajmahal Hills and shallow in Rajasthan and Assam. According to recent computations of seismic soundings, the maximum depth of the alluvium upto the basement rocks is about 6100 m. The depth of alluvial deposits at some important locations are Meerut (1066.8 m.), Kalyan (2286.0 m.) Dehradun (5123.8 m.) and Siliguri (5577.8m).

Extreme horizontality of this monotonous plain is its chief characteristic. Whereas its average elevation is about 200 m. above mean sea level, its highest elevation is 291 m. above mean sea level between Ambala and Saharanpur. The comparatively high area near Ambala forms the watershed which divides the drainage system of the Ganga from that of the Indus. It is, in fact, a low land and is hardly perceptible as one enters Punjab-Haryana plain from the Uttar Pradesh plains. Its average gradient for about 1500 kms. from Saharanpur to Calcutta is 20 cm. per km. and it decreases to 15 cm. per km. from Varanasi to Ganga delta.

ORIGIN OF THE PLAIN

It is almost universally accepted that this vast plain has been formed as a result of filling of a deep depression lying between the Peninsular and the Himalayan region by the depositional work of the rivers coming from these two landmasses. However, divergent views have been expressed regarding the origin of this great depression and the process of filling it. Wadia postulates that these plains were originally a deep depression or furrow lying between the Peninsula and the mountain region. The great Austrian geologist Edward Suess has suggested that it was a "Fore-deep" fronting the Himalayan earth-waves, a "*sagging*"- or subsidence of the northern part of the Peninsula as it arrested the southward advance of the mountain waves. Sir Sydney Burrard, on the other hand thinks that the Indo-Gangetic alluvium conceals a great deep rift, or fracture, in the earth's ub-crust, several thousand metres deep, the hollow being subsequently filled up by detrital. He ascribes to such sub-crustal cracks or rifts a fundamental importance in geotectonics and attributes the elevation of the Himalayan chain to an incidental bending or curbing movement of the northern wall to the fissure. Such sunken tracts between parallel, vertical dislocations are called '*Rift Valleys*'. The rift valley between the Himalayan ranges and the Peninsula which gave birth to this plain was about 2400 km. long and hundreds of metres deep. His findings were based on some anomalies in the observations of the deflections of the plumb line and other geodetic considerations. He described some other rift valleys of the Himalayan region as well as the rift valleys of Narmada and Tapi in the Peninsular India. Scholars like Hayden and R.D. Oldham as well as other geologists of the Geological Survey of India have not accepted Burrard's view of the Indo-Gangetic depression. The main objection to Burrard's views is that there is no trace of a rift valley at the northern edge of the Peninsula and that such a vast rift valley is not possible.

According to the recent views expressed by many geologists and geographers, sediments deposited at the bed of the Tethys Sea was folded and warped due to northward drift of the Peninsula. Consequently the Himalayas and a trough to the south were formed. The origin of this depression or trough, lying at the foot of the mountain, is doubtless intimately connected with the latter. The Great plain represents the infilling of the foredeep warped down between the advancing Peninsular Block and the Himalayas. The infilling has been done by the deposition of the detritus of the mountain brought by the numerous rivers emerging from them during the period of great gradational activity. Geologically most parts of this plain are of the Pleistocene and Recent formations. Thus, the surface deposits of this tract belong to the last chapter of the earth's history and conceal beneath them the older peninsular and other formations.

GEOMORPHOLOGY OF THE PLAIN

There is a tendency amongst geographers to treat the Great Plain of North India as a monotonous, flat and featureless plain; but it has its own geomorphological varieties which have their own significance. The following geomorphological features may be noticed depending upon the nature of relief and soil structure.

The Bhabar is a narrow belt about 8-16 km. wide running in east-west direction along the foot of the Shiwaliks with a remarkable continuity from the Indus to the Tista. Rivers descending from the Himalayas deposit their load along the foothills in the form of alluvial fans. These fans, consisting of gravel and unassorted sediments, have merged together to build up the bhabar belt which forms the northern boundary of the Great Plain. The porosity of the pebble studded rock beds is so high that most of the streams sink and flow underground. Therefore the area is marked by dry river courses except in the rainy season. The Bhabar belt is comparatively narrow in the east and extensive in the western and' norths-western hilly region.

The Tarai is a 15-30 km. wide marshy tract in the south of Bhabar running parallel to it. It is marked by the re-emergence of the underground streams of the Bhabar belt. The re-emerged water converts large areas along the rivers into ill- drained marshy lands of excessive dampness covered with thick forests giving shelter to a variety of wild life. Most of the Tarai land has been reclaimed and turned into agricultural land.

The Bhangar is composed of old alluvium of the Middle Pleistocene age and forms the alluvial terrace above the level of flood plains. It is often impregnated with colcareous concretions known as kankar. Remnants of the Bhangar are eroded by every change in the direction of river channels, and are being levelled down by their meandering tendencies.

The Khadar is composed of newer alluvium and forms the flood plains along the river banks. A new layer of alluvium is deposited by river flood almost every year. These deposits are normally confined to the vicinity of the present river channels. The clays have less kankar, and the organic remains entombed in them belong to still living species. The *khadar* imperceptibly merges into the deltaic and other accumulations of prehistoric times.

Reh or Kallar comprises barren saline efflorescences of drier areas in Uttar Pradesh and Haryana. Reh areas have spread in recent areas with increase in irrigation.

Bhur denotes an elevated piece of land situated along the banks of the Ganga river especially in the upper Ganga-Yamuna Doab. This has been formed due to accumulation of wind-blown sands during the dry hot months of the year.

REGIONAL DIVISIONS OF THE GREAT PLAIN OF INDIA

Although, the Great Plain of North India is treated as a geographical unit with low elevation and gentle slope, this vast area exhibits distinctive fluvial patterns, directions of flow and geomorphology in different parts allowing it to be divided into the following four major regions: (Fig. 2.6).

1. The Rajasthan Plain.
2. The Punjab-Haryana Plain.
3. The Ganga Plain.
4. The Brahmaputra Plain.

1. The Rajasthan Plain

The western extremity of the Great Plain of India consists of the *Thar* or the *Great Indian Desert* which covers the western Rajasthan and the adjoining parts of Pakistan. The desert is about 650 km. long and 250-300 km. wide. Its total area is about 2.0 lakh sq. km. out of which 1.75 lakh sq. km lies in India. About two thirds of the Indian desert lies in Rajasthan, west of the Aravali Range, and the remaining one third is in the neighbouring states of Haryana, Punjab and Gujarat. Recently, some geomorphic studies by using remote sensing techniques in conjunction with ground truth were undertaken by the Central Arid Zone Research Institute, Jodhpur. This vast desert is an undulating plain whose average elevation is about 325 m. above mean sea level. It descends to about 150 m. above mean sea level near the Indo-Pak border as well as towards the Indus Valley and the Rann of Kachchh. The desert proper is called *Marusthali* and accounts for greater part of the *Marwar* plain. The average elevation of the *Marusthali* is 200-250 m. above sea level. It has a vast stretch of sand with a few outcrops of bedrock of gneisses, schists and granites which proves that geologically it is a part of the Peninsular Plateau and it is only at the surface that it looks like an aggradational plain. In general, the eastern part of the Marusthali is rocky while its western part is covered by shifting sand dunes locally known as *dhrian*.

The eastern part of the Thar Desert, upto the Aravali Range is a semi-arid plain which is known as the *Rajasthan Bagar*. It runs in a north-east to south-west direction from the edge of the Aravalli in the east to the 25 cm. isohyet in the west. It is drained by a number of short seasonal streams originating from the Aravali and supports agriculture in some patches of fertile tracts called *rohi*. Even the important river, the Luni, is a seasonal stream which flows towards the south-west to the Rann of Kuchchh. The tract north of the Luni is known as *thali* or sandy plain.

The LANDSAT black and white products have been used to study the geomorphological characteristics of this Great Desert including its sand dunes. Based on the morphological, spatial and spectral characteristics, six types of sand dunes, viz. obstacle, parabolic, longitudinal, transverse, barchan and shrub-coppice have been identified in this desert. The fear height of the dunes varies from 8 m. in Jaipur and Sikar districts to 30 m. in Banner district. The length of the dunes also varies greatly and some may be 5-10 km. long.

North of the Luni basin, there is a large area of inland drainage on the eastern edge of the Thar Desert having several saline lakes. They are a great source of common salt and many other salts. The *Sambhar*, the *Didwana*, The *Degana*, the *Kuchaman*, the *Sargol* and the *Khatu*. are some of the important lakes.

The largest and the most outstanding is the Sambhar lake about 65 km. west of Jaipur. Situated at an altitude of about 360 m. in the Aravali terrain, this lake is about 30 km. long with an average width of 3-8 km. It occupies an area of about 225 sq. km. during the rainy season but shrinks considerably in dry season.

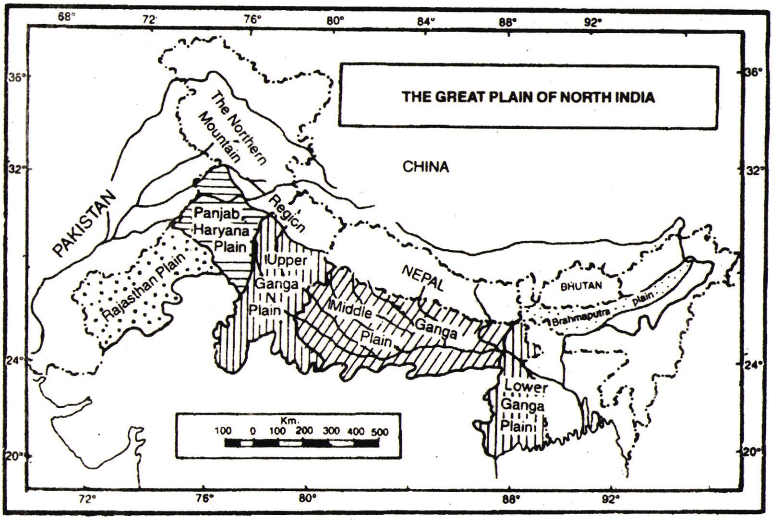
68°
72°
76°
80°
84°
88°
92°
36°
32°
24°
20°
THE GREAT PLAIN OF NORTH INDIA
CHINA
The Northern Mountain Region
PAKISTAN
Panjab Haryana Plain
Rajasthan Plain
Upper Ganga Plain
NEPAL
Middle Ganga Plain
BHUTAN
Brahmaputra plain
Lower Ganga Plain
Km.
100 0 100 200 300 400 500

Fig. 5.10 : Regional Divisions of the great Plain of North India.

2. The Punjab-Haryana Plain

The Great Indian Desert imperceptibly gives way to the fertile plains of the Punjab and Haryana towards the east and north east. The entire plain extends for a length of 640 km. in north-west to south-east direction and is about 300 km. wide in east-west direction. The total area of this plain is above 1.75 lakh sq. km. Its eastern boundary in Haryana is formed by the Yamuna river. The average elevation of the plain is about 250 m. above mean sea level. Its northern part is nearly 300 m. above mean sea level and it drops to about 200 m. in the south-east. Part of the plain shows a flat to slightly convex planation controlled by subsurface Delhi-Aravali ridge.

The part of the plain, formed as a result of alluvial deposits by five rivers, viz., the Satluj, the Beas, the Ravi, the Chenab and the Jhelum, is known as the Punjab Plain—*the land of five rivers*. It is primarily made up of 'doabs'—*the land between two rivers*. From east to west these doabs are as under:

(a) Bist-Jalandhar Doab, lying between the Beas and the Sutluj;

(b) Bari Doab, between the Beas and the Ravi;

(c) Rechna Doab, between the Ravi and the Chenab;

(d) Chaj Doab, between the Chenab and the Jhelum; and the

(e) Sind Sagar Doab, between the Jhelum-Chenab and the Indus.

The depositional process by the rivers, continuing since long, has united these doabs and has given a homogenous geomorphological entity to the entire area. However, the mass of alluvium has been broken by the river courses which have carved for themselves broad flood plains of khadar flanked by bluffs, locally known as *dhaya*. These bluffs, as high as 3 metres or more, have been heavily gullied. The *khadar* belt, known as *bet lands*, though liable to flooding, is agriculturally valuable.

The northern part of this plain adjoining the Shiwalik hills has been intensively eroded by numerous streams called Chos.

This has led to enormous gullying. The erosion by the Chos is particularly noticed in Hoshiarpur district of Punjab. In a short stretch of about 130 km. nearly a hundred Chos debouch on the plains. Majority of these Chos join the White Bein and the Black Bein, both joining the Satluj. About 32 km. wide belt of Chos is rendered infertile. To the south of the Satluj River, there is Malwa plain of Punjab.

The area between the Ghaggar and the Yamuna rivers lies in Haryana and is often termed as '*Haryana Tract*'. It acts as water-divide between the Yamuna and the Satluj rivers. The only river between the Yamuna and the Satluj is the Ghaggar which is considered to be the present day successor of the legendary *Saraswati River*.

3. The Ganga Plain

This is the largest unit of the Great Plain of India stretching from Delhi to Calcutta in the states of Uttar Pradesh, Bihar and West Bengal covering an area of about 3.75 lakh sq. km. The Ganga is the master river after whose name this plain is named. The Ganga along with its large number of tributaries originating in the Himalayan ranges viz., the Yamuna, the Gomati, the Ghaghara, the Gandak, the Kosi, etc. have brought large quantities of alluvium from the mountains and deposited here to build this extensive plain. The peninsular rivers such as Chambal, Betwa, Ken, Son, etc. joining the Ganga river system have also contributed to the formation of this plain. The general slope of the entire plain is to the east and south east. Depending upon its geographical variations, this plain can further subdivided into the following three divisions:

(a) The Upper Ganga Plain

(b) The Middle Ganga Plain

(c) The Lower Ganga Plain.

(a) The Upper Ganga Plain

Comprising the upper part of the Ganga Plain, this plain is delimited by the 300 m. contour in Shiwaliks in the north, the Peninsular boundary in the south and the course of the Yamuna river in the west. Its eastern boundary is rather obscure and has become a controversial topic among geographers. The limit drawn by L.D. Stamp and later adopted by O.H.K. Spate, roughly corresponding with 100 cm. *isohyet* seems to be far from being practical. Physiographically, the 100 m. contour has been accepted by the geographers as the most effective line of demarcation. This plain is about 550 km. long in the east-west direction and nearly 380 km. wide in north-south direction, covering an approximate area of 1.49 lakh sq. km. Its elevation varies from 100 to 300 m. above mean sea level. The plain is drained by the Ganga and its tributaries like the Yamuna, the Ram Ganga, the Sarda, the Gomti and the Ghaghara rivers. Almost all the river follow NW-SE course concomitant with the lies of the land. The average gradient of the land is about 25 cm. per km. The gradient is comparatively steep in the northern part. The rivers flow sluggishly in the plain as the gradient decreases. The monotony of this flat and featureless plain is broken by the Tarai- Bhabar submontane belt and on micro level by the river bluffs, river meanders and oxbow lakes, levees, abandoned river courses, sandy stretches (Bhurs) and the river channels themselves. The western part of this plain comprises of comparatively higher Ganga-Yamuna Doab. East of this doab are the low lying Rohilkhand and plains which merge into the Avadh plains further east. The Ghaghara is the main stream of the Avadh Plains. The khadar of this river is very wide because the river meanders through this area. Moreover it often changes its course. At places this khadar is 55 km. wide. Consequently, there is a consistent fear of devastating floods.

(b) The Middle Ganga Plain

To the east of the Upper Ganga plain is Middle Ganga plain occupying eastern part of Uttar Pradesh and northern part of Bihar. It measures about 600 km. in east-west and nearly 330 km. in north-south direction accounting for a total area of about 1.44 lakh sq. km. Its northern and southern boundaries are well defined by the Himalayan -foothills and the Peninsular edge respectively. Its western and eastern boundaries are rather ill defined and the region is wide open on both the sides giving it the personality of the *east-west continuum* of the vast isotropic Ganga Plain. There is no physical boundary worth the name and the plain imperceptibly opens up in the west from out of the upper Ganga Plain and so invisibly dies out into the lower Ganga Plain in the east. As such, it is *a transitional region par excellence*, interposed in the enormity of the Ganga Valley. However, several efforts have been made to demarcate the western and the eastern boundaries of this transitional zone. The most accepted boundaries are those made by 100 m. contour in the west, 75 m. contour in the north-east and by 30 m. contour in the south-east. Obviously this is a very low plain, no part of which exceeds 150 m. in elevation.

This plain is drained by the Ghaghara, the Gandak and the Kosi rivers, all tributaries of Ganga coming from the Himalayas. These rivers are responsible for filling up with alluvial deposits of 2,000 metre deep trough at the foot of the Nepal Himalayas. They flow sluggishly in this flat land as a result of which the area is marked by local prominences such as levees, bluffs, oxbow lakes, marshes, tals, ravines, etc. The kankar formation is comparatively less due to the preponderance of the *khadar*. Almost all the rivers keep on shifting their courses making this area prone to frequent floods. The Kosi river is very notorious in this respect. It used to flow near Purnea in 1736 and now its course is about 110 km. west of it. At occasions its water level has risen by 10 metres in short span of 24 hours. It has long been called the '*Sorrow of Bihar*'. Strenuous efforts both by India and Nepal are being made to tame this river. The major units of this plain are Ganga-Ghaghara doab, Ghaghara-Gandak doab and Gandak-Kosi doab (Mithila Plain).

Some rivers join the Ganga from the south also, the Son river being the most important. Here the gradient is steep, 45 cm. per km., as compared to 9-10 cm. per km. in east Uttar Pradesh and only 6 cm. per km. in the Mithila Plain. East of Sone river is the Magadh Plain.

(c) The Lower Ganga Plain

This plain includes the Kishanganj tehsil of Purnea district in Bihar, the whole of West Bengal (excluding the Purulia district and the mountainous parts of Darjeeling district) and most parts of Bangladesh. It measures about 580 km. from the foot of the Darjeeling Himalaya in the north to Bay of Bengal in the south and nearly 200 km. from the Chotanagpur Highlands in the West to the Bangladesh border in the east. The total area of this plain is about 81 thousand sq. km. Its width varies greatly and it narrows down to a mere 16 km. between the Rajmahal Hills and the Bangladesh border. The 50 m. contour roughly corresponds with its western boundary. The northern part of this plain has been formed by die sediment deposited by the Tista, Jaldhaka and Torsa. Besides, this area is marked by the Duars (Darjeeling Tarai) and the Barind plain, a tract of old alluvium between the Kosi-Mahananda corridor in the west and the river Sankosh in the east. The delta formation accounts for about two-thirds of this plaint This is the largest delta in the world. The Ganga river divides itself into several channels in the delta area. The slope of the land here is a mere 2 cm. per km. Two thirds of the area is below 30 m. above mean sea level. The entire land upto Calcutta would be completely submerged if the sea level rose by only 7 metre. The seaward face of the delta is studded with a large number of estuaries, mud flats, mangrove swamps, sandbanks, islands and forelands. Large part of the coastal delta is covered by thick impenetrable tidal forests. These are called the *Sunderbans* because of the predominance of *Sundri* tree here.

4. The Brahmaputra Plain

This is also known as the Brahmaputra valley or Assam Valley or Assam Plain as most of the Brahmaputra valley is situated in Assam. Though, often treated as the eastern continuation of the Great Plains of India, it is a well- demarcated physical unit girdled by the Eastern Himalaya of Arunachal Pradesh in the north, Patkai and Naga Hills in the east and the Garo-Khasi-Jaintia and Mikir Hills in the south. Its western boundary is formed by the Indo-Bangladesh border as well as the boundary of the lower Ganga Plain. Extending from the easternmost end of Assam near the syntaxial bend of the Eastern Himalayas to the west of Dhubri near the Bangladesh border this plain is about 720 km. long and its average width is 60-100 km. The entire plain covers an area of about 56 thousand sq. km. It is an aggradational plain built up by the depositional work of the Brahmaputra and its tributaries. The Brahmaputra river enters this plain near Sadiya and flows farther to

Bangladesh after turning southwards near Dhubri. The general level of the plain varies from 130 m. in the east to 30 m. in the west. The average gradient of the land is 12 cm. per km. in the N.E. to S.W. direction. The area is well demarcated by 150 m. contour beyond which the surrounding hill terrain dominates the scene. The northern margin has steep slope from the foothills of Arunachal Pradesh but the southern margin is marked by gradual fall from the hill ranges. The innumerable tributaries of the Brahmaputra river coming from the north debouch abruptly to the main valley and form a number of alluvial fans. Consequently, the tributaries branch out in many channels giving birth to river mendering leading to formation of bills and ox-bow lakes. There are large marshy tracts in this area. The alluvial fans formed by the coarse alluvial debris have led to the formation of tarai or semi-tarai conditions. Some southern tributaries also have meandering course and there area good number of bills and oxbow lakes.

THE PENINSULAR PLATEAU

The Peninsular Plateau of India is roughly triangular in shape with base coinciding with the southern edge of the great plain of North India and its apex is formed by Kanniyakumari in the southern extremity. The northern boundary of the Peninsular block is an irregular line running from Kuchchh along the western flank of the Aravali range to near Delhi, and thence roughly parallel to the Yamuna and the Ganga as far as the Rajmahal Hills and the Ganga Delta. It is surrounded by the hill ranges on all the three sides. To its north are the Aravali Range, the Vindhya, the Satpura, the Bharmer and the Rajmahal Hills. To the south of about 22°N latitude, the Western Ghats (The Sahyadris) and the Eastern Ghats form its western and eastern boundaries respectively. The entire plateau measures about 1,600 km. in north-south and 1,400 km. in east-west direction. It covers a total area of about 16 lakh sq. km. which is about half of the total land area of the country. It is thus the largest physiographic unit of India. The average height of the plateau is 600-900 m. above sea level although many parts are well over 1000 m. The general slope of the plateau is from west to east with the exception of Nanda-Tapi rift which slopes westwards.

The Peninsular Plateau is an ancient tabular block composed mostly of the Archaean gneisses and schists. It has been a stable shield which has gone through little structural changes since its formation. Ever since the dawn of geological history the Peninsula has been a land area and has never been submerged beneath the sea except in a few places where marine transgressions have been made and that too locally and temporarily.

Undoubtedly, the entire Peninsular Plateau is an aggregation of several small plateaus and hill ranges interspersed with river basins and valleys. A brief description of these plateaus, hill ranges and the intervening river valleys will be of great help in describing the relief of this great plateau.

THE INDIAN ISLANDS

Apart from the large number of islands in the near proximity of the Indian coast, there are two main groups of islands in the Indian Ocean far away from the coast. One of them is the Andaman and Nicobar Archipelago in the Bay of Bengal and the other is a group of tiny islands known as the Lakshadweep Islands in Arabian Sea. These islands have gained much importance and their study has become almost indispensable in view of the increasing interest of super powers in the geopolitics of the Indian ocean.

The Andaman and Nicobar group of islands form an arcuate chain, convex to the west, extending from 6° 45' N to 13° 45' N and from 92° 10' E to 94° 15' E for a distance of about 590 km. with a maximum width of about 58 km. This archipelago is composed of 265 big and small islands covering a cummulative area of about 8249 sq. km.

The entire chain consists of two distinct groups of islands. The Great Andaman group of islands in the north is separated by the *Ten Degree Channel* from the Nicobar group in the south. The Andaman is a closely knit group of about 203 islands. It is 260 km. long and 30 km. wide with a total area of 6596 sq. km. This group of islands is divided into three major groups viz. North Andaman, Middle Andaman and South Andaman. Little Andaman is separated from the Great Anadmans by 50 km. wide Duncan Passage.

The Nicobar group of islands consists of 7 big and 12 small islands together with several tiny islands. They are scattered over a length of 262 km. with maximum width of 58 km. covering an area of 1653 sq. kms. The Great Nicobar, as its name suggests, is the largest island measuring 50 × 25 km. It is the southernmost island and is only 147 km. away from Sumatra island of Indonesia.

Most of these islands are made of tertiary sandstone, limestone and shale resting on basic and ultrabasic volcanoes. The Barren and Narcondam islands, north of Port Blair, are volcanic islands. Some of the islands are fringed with coral reefs. Many of them are covered with thick forests and some are highly dissected. Most of the islands are mountainous and reach considerable heights. Saddle peak (737 m.) in North Andaman is the highest peak.

The Lakshadweep Islands in the Arabian Sea, though literally mean one lakh islands is only a group of 25 small islands. They are widely scattered over an area of 108.78 sq. kms. extending from 8° N to 12° 20' N and 71° 45' E to 74°E about 200-500 km. south-west of the Kerala coast. The islands north of 11° N are known as *Amendivi Islands* while those south of this latitude are called *Cannanore Islands*. In the extreme south is the Minicoy island. All are tiny islands of coral origin and are surrounded by fringing reefs. The largest and the most advanced is the Minicoy island with an area of 4.53 sq. km. Betra has only 0.12 sq. km. area. Most of the islands have low elevation and do not rise more than five metre above sea level. Their topography is flat and relief features such as hills, streams, valleys, etc. are conspicuous by their absence. Shallow lagoons are seen on their western side, while on the eastern seaboard the slopes arc steeper.

SIGNIFICANCE OF THE PLAINS

With its fertile alluvial soils, flat surface, slow moving perennial rivers and favourable climate, the Great Plain of North India is of great significance. It is the home of about half of the Indian population although it accounts for less than one fourth of the total area of the country. The plain supports some of the highest population densities depending upon purely agro-based economy in some of these areas. The extensive use of irrigation has made some parts of this plain, especially Punjab, Haryana and western part of Uttar Pradesh the *granary of India*. The entire plain except the Thar Desert, has a close network of roads and railways which has led to large scale industrialisation and urbanization. The development of trade and commerce in this plain is a natural sequal of industrialization and urbanization. There are many religious places along the banks of the sacred rivers like Ganga and Yamuna which are very dear to Hindus. Here flourished the religions of Budha and Mahavira and the movements of Bhakti and Sufism. In short this vast plain is the hearthrob of India and constitutes its very soul.

THE PLATEAUS OF THE PENINSULA INDIA

1. The Marwar Upland

This is also called the Upland of eastern Rajasthan as it lies in the east of the Aravali Range. The average elevation of this area is 250-500 m. above sea level and it slopes down eastwards. It is made up of sandstone, shales and limestones of the Vindhayan period. The Banas river originates in the Aravali Range and flows for about 400 km. before joining the Chambal river. The area has been carved into a rolling plain by the erosional work of the Banas river and its tributaries.

2. The Central Highland

Also called the *Madhya Bharat Pathar* is in the east of the Marwar Upland. Most of it comprises of the basin of the Chambal river which flows in a rift valley. The *Sindh* and the Parbati are its main tributaries. It is an open rolling plateau made of old rocks which is interspersed with rounded hills composed of sandstone. Thick forests grow here. To the north are the *ravines or badlands* of the Chambal river.

3. The Bundelkhand

To the south of the Yamuna river between the Madhya Bharat Pathar and the Vindhyan Scarplands is the old dissected upland of the 'Bundelkhand gneiss' comprising of granite and gneiss. This is called Bundelkhand upland. With an average elevation of 300-600 m. above sea level, this area slopes down from the Vindhyan Scarp toward the Yamuna River. The area is recognised by a mass of rounded hummocky hills made of granite and sandstone. The erosional work of the rivers flowing here has converted it into an undulating area and rendered it unfit for cultivation.

4. The Malwa Plateau

The Malwa Plateau roughly forms a triangle based on the Vindhyan Hills, bounded by the Aravali Range in the west and sharply defined scarp overlooking Bundelkhand in the east. The plateau inherits a complex geology; scarcely any one of the peninsular groups is unrepresented here. It is drained by the north flowing Chambal and many of its right bank tributaries like the Kali, the Sindh and the Parbati. It also includes the upper courses of the Sindh, the Ken and the Betwa. It is composed of extensive lava flow and is covered with black soils. The general height decreases from 600 m. in the south to less than 500 m. in the north. There are rolling surfaces and flattopped hills dissected by rivers flowing through the area. In the north the plateau is marked by the Chambal ravines.

5. The Baghelkhand

East of the Maikal Range is the Baghelkhand made of limestones and sandstones on the west and granite in the east. It is bounded by the Son river on the north, and to its south occur anticlinal highlands and synclinal valleys of sandstones and limestones. The central part of the plateau acts as a water divided between the Son drainage system in the north and the Mahanadi river system in the south.

6. The Chotanagpur Plateau

East of Baghelkhand, the Chotanagpur plateau represents the north-eastern projection of the Indian Peninsula. It covers mostly south Bihar, the adjoining eastern fring of Madhya Pradesh and Purulia district of West Bengal. The Son river flows in the north-west of the plateau and joins the Ganga. The average elevation of the plateau is 700 m. above sea level. This plateau is composed mainly of Gondwana rocks with patches of Archaean granits and gneisses and Deccan Lavas. The Chotanagpur plateau virtually consists of a series of plateaus standing at different levels of elevation. The highest general elevation of about 1,100 m. is in the mid-western portion known as the '*Pat* lands (high level laterite plateau). From here. the land descends in all directions in a series of steps which are marked by waterfalls across the rivers. The plateau is drained by numerous rivers and streams in different directions and presents a *radial drainage* pattern. Rivers like the Damodar, the Subarnrekaha, the North Koel, the South Koel and the Barkar have developed extensive drainage basins. The Damodar river flews through the middle of this region in a rift valley from west to east. Here are found the Gondwana coal fields which provide bulk of coal in India.

North of the Damodar river is the *Hazaribagh plateau* with an average elevation of 600 m. above mean sea level. This plateau has isolated hills; Parasnath in the east rises to 1366 m. The area is made of granites and gneisses while the hills have quartz rocks. It looks like a peneplain due to large scale erosion.

The *Ranchi Plateau* to the south of the Damodar Valley rises to about 600 m. above mean sea level. The maximum height is found in western parts where *pats of high mesas* capped with laterite steeply rise to an altitude of about 1100 m. The *Netarhat Pat* and *Goru* rise to 1119 and 1142 m above sea level respectively. Most of the surface is rolling where the city of Ranchi (661 m) is located. At places it is interruped by monodnocks and conical hills.

The *Rajmahal Hills* forming the north eastern edge of the Chotanagpur Plateau are mostly made of basalt and are covered by lava flows. They run in north-south direction and rise to average elevation of 400 m. (highest mount is 567 m.) These hills have been dissected into separate plateaus.

7. The Meghalaya Plateau

The rocks of the peninsular plateau of India extend further north-east beyond the Rajmahal hills and form a rectangular block known as the Meghalaya or the Shillong plateau. This plateau has been separated from the main block of the peninsular plateau by a wide gap known as the *Garo-Rajmahal Gap*. This gap was formed by down-faulting and was later on filled by sediments deposited by the Ganga. Extending over an area of about 35 thousand sq. km. this plateau is largely formed by Archaean (Dharwarian) quartizites, shales and schists with granite intrusions and some basic silts. The plateau slopes down to Brahmaputra valley in the north and the Surma and Meghna valleys in the south. Its western boundary more or less coincides with the Bangladesh border. The western, central and the eastern parts of the plateau are known as the Garo Hills (900 m) the Khasi-Jaintia Hills (1500 m) and the Mikir Hills (700 m). Shillong (1961 m) is the highest point of the plateau.

8. The Deccan Plateau

This is the largest unit of the Peninsular Plateau of India covering an area of about five lakh sq. km. This triangular plateau is bounded by the Satpura and the Vindhya ranges in the north-west, the Mahadev and the Maikal in the north, the Western Ghats in the west and the Eastern Ghats in the east. With average elevation of 600 m. it rises to 1000 m. in the south but dips to 500 m. in the north. Its general slope is from west to east which is indicated by the flow of its major rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery. These rivers have further subdivided this plateau into a number of smaller plateaus described as under:

(a) *The Maharashtra Plateau* lies in Maharashtra and forms the northern part of the Deccan Plateau. Much of the region is underlain by basaltic rocks of lava origin . The area looks like a rolling plain due to weathering. The horizontal lava sheets have led to the formation of typical *Deccan Trap* topography. The broad and shallow valleys of the Godavari, the Bhima and the Krishna are flanked by flat-topped steep sided hills and ridges. The Ajanta range lies to the south of the Tapi river. The entire area is covered by black cotton soil known as regur.

(b) *The Karnataka Plateau* also known as the Mysore plateau lies to the south of the Maharashtra plateau.

Made up primarily of the Archaean formations, it is a rolling country with an average elevation of 600-900 m. It is highly dissected by numerous rivers rising from the Western Ghats. It contains the heads of the *Tungabhadra* and the *Cauvery rivers*. The general trend of the hills is either parallel to the Western Ghats or athwart it. The highest peak (1913 m) is at Mulangiri of *Baba Budan* Hills in Chikmaglaur district. The plateau is divided into two parts called *Malnad and Maidan*. The *Molnad* in Kanada means hilly country. It is dissected into deep valleys covered with dense forests. The *Maidan* on the other hand is formed of rolling plain with low granite hills. The plateau tappers between the western and the eastern ghats in the south and merges with the Niligiri hills there.

(c) *The Telangana plateau* in Andhra Pradesh consists of Archaean gneisses at an average elevation of 500-600 m. The southern part is higher than its northern counterpart. The region is drained by three river systems, the Godavari, the Krishna and the Penneru. The entire plateau is divided into two major physiographic regions, namely, the Chats and the Peneplains.

9. The Chhattisgarh Plain

The Chhattisgarh plain is the only plain worth the name in the vast stretch of plateaus and hill ranges of the Peninsular plateau. It is a saucer shaped depression drained by the upper basin of the Mahanadi. The whole basin lies between the Maikala Range and the Orissa hills. The region was once ruled by *Haithaivanshi Rajputs* from whose thirty six forts (*chhatisgarh*) it derives its name. The basin is laid with nearly horizontal beds of limestone and shales deposited during the Cuddapah age. The general elevation of the plain ranges from 250 m. in the east to 330 m. in the west.

HILL RANGES OF THE PENINSULA

The above mentioned plateaus of the Peninsula are separated from one another by hill ranges and river valleys. The hills of the Peninsular India are much lower than the

Himalayan ranges. Most of these hills are of the relict type, being remnants of the originally larger hills but some typical horsts are also seen. Some of the important hill ranges are described as under:

1. The Aravali Range

One of the major physiographic elements of the Peninsular India is the Aravali range running in a north-east to south-west direction for 800 km. between Delhi and Palanpur (near Ahmadabad) in Gujarat. The Aravalis represent the relict of the world's oldest mountain formed as a result of folding at the close of the Archaean era. Obviously, their dimensions were much larger and probably even bigger than the present Himalayas. Although its north-eastern end is marked by the Delhi ridge, it is supposed to continue upto Haridwar burried under the allivium of the Great Plains. M.S. Krishnan, has expressed the view that one branch of the Aravalis extends to the Lakshadweep Archipelago through the Gulf of Khambhat and the other into Andhra Pradesh and Karnataka. According to. D.N. Wadia, the Aravalis were a prominent feature in the old Palaeozoic and Mesozoic periods and extended as continuous chain of lofty mountains from Deccan to possibly beyond Garhwal. What we at present see of them are the eroded remnants of these mountains; their mere stumps laid bare by repeated cycles of erosion.

S.P. Chatterjee has brought out some interesting features of the Aravali Range According to the conclusion drawn by him, the Aravali, which occupies the site of an ancient geosyncline and was uplifted and folded in synclinorium for the first time during the *Algonkian* age, 600 to 700 million years ago. The present Aravali has lost its range character in many parts and is now a relic of what it was in the past when it formed India's main watershed, extending from Kumaon Himalaya to the farthest end of the Peninsular plateau on the south, and perhaps one of its arms reaching eastwards across Central India. In that remote age several of its summits rose above the snow-line and nourished glaciers of stupendous magnitude, which in their turn fed many rivers. This range was later reduced by long continuous erosion almost to sea level. There is evidence to suggest that in the late Mesozoic times, perhaps about 100 million years ago, the peneplaned Aravali was uplifted for the second time by at least 1200 m. near Udaipur, and. 200 m. at its two ends near Delhi and Ahmadabad.

Although, its general elevation is only 400-600 m., parts of this range rise well above 1,000 m. The Aravali range has a lower elevation between Delhi and Ajmer where it is characterised by a chain of detached and discontinuous ridges. However, it becomes a continuous range south of Ajmer where it rises to 900 m. At the south-west extrimity the range rises to over 1,000 m. Here Mt. Abu (1158 m.), small hilly block, is separated from the main range by the valley of the Banas. Guru Sikhar (1,722 m) the highest peak is situated in Mt. Abu. Barr, Pipli Gnat, Dewair and Desuri passes allow movements by roads and railways.

2. The Vindhya Range

The Vindhaya range rises as an escarpment flanking the northern edge of the Narmada-Son Trough overlooking the Narmada valley. It runs more or less parallel to the Narmada Valley in an east-west direction for a distance of over 1200 km. The general elevation of the Vindhya Hills is 300 to 650 m. and it rarely goes above 700 m. The northern slope of this range is rather gentle and there are no well marked spurs, steep falls and valleys. Most parts of the Vindhayan range are composed of horizontally bedded sedimentary rocks of ancient age. The western part of this range is covered with lava. The Vindhayas are continued eastwards as the *Bharner* and *Kaimur* hills. The Vindhya- Kaimur scarp exceeds 610 m. only at few places. This range acts as a watershed between the Ganga system and the river systems of south India. The rivers Chambal, Betwa and Ken rise within 30 km. of the Narmada.

3. The Satpura Range

'*Sat*' in Sanskrit means seven and '*pura*' means mountains. Therefore, the Satpura range is a series of seven mountains. It runs in an east-west direction south of the Vindhyas and in between the Narmada and the Tapi rivers, roughly parallel to these features. Commencing from the Rajpipla Hills in the west, through the Mahadev Hills to the Maikala Range, it stretches for a distance of about 900 km. These hills appear to be affected by tectonic disturbances. There are evidences that parts of the Satpuras have been folded and upheaved. They are regarded as structural uplift or 'hoarst'.

No other east-west tectonic mountain of Peninsular India is as high as the Satpura. Most of the hills rise to elevation of 900 to 1000 m. Dhupgarh (1350 m.) near Panchmarhi on Mahadev Hills is the highest peak. The other peaks are the Astamba Dongar (1325 m) and Amarkantak (1127 m.).

4. The Western Ghats (or The Sahyadris)

Forming the western edge of the

Deccan tableland, the Western Ghats run in north- south direction, parallel and close to the Arabian Sea coast, from the Tapi valley (21°N latitude) to a little north of Kanniyakumari (11°N latitude) for a distance of 1600 km. As the name implies, the Western Ghats are, down to Malabar, steep-sided, terraced, flat-topped hills or cliffs presenting the mesa-like stepped topography facing the Arabian Sea coast. This is due to the horizontally bedded lavas, which on weathering, have given a characteristic 'landing stair aspect' to the relief of this mountain chain. South of Malabar, the Nilgiris, Anamalai, etc. present quite different landscape due to the difference in geological structure. The Western Ghats abruptly rise as a sheer wall to an average elevation of 1,000 m. from the Western Coastal Plain and appear to be an imposing mountain. But they slope gently on their eastern flank and hardly appear to be mountain when viewed from the Deccan tableland.

The northern section of the ghats from 21°N to 16°N latitudes *i.e.* from Tapi valley to little north of Goa is made of horizontal sheets of Deccan lavas forming a formidable wall looking over the West Coastal Plain. The average height of this section of the Ghats is 1,200 m. above sea level, but some peaks attain more heights. Kalasubai (1,646 m.) near Igatpuri, Salher (1,567 m.) about 90 km. north of Nasik, Mahabaleshwar (1,438 m.) and Harishchandragarh (1,424 m.) are important peaks. Thalghat and Bhorghat are important passes which provide passage by roads and railways between the Konkan Plains in the west and the Deccan Plateau in the east. LANDSAT imagery shows a large density of faults along the trend of the Ghats.

The Middle Sahyadri runs from 16°N latitude upto Nilgiri hills. This part is made of granites and gneisses and presents rougher topography. Lying at a stone's throw from the Arabian Sea coast, this area is covered with dense forests. The western scarp is considerably dissected by headward erosion of the west flowing streams. The average height is 1200 m. but many peaks exceed 1500 m. The Vavul Mala (2,339m.), the Kundremukh (1,892 m.) and Pashpagiri (1,714 m.) are important peaks. The Nilgiri Hills which join the Sahyadris near Gudalur rises abruptly to over 2,000 m. and marks the junction of the Western Ghats with Eastern Ghats. Doda Betta (2,637 m.) and Makurti (2,554 m.) are important peaks of this area.

The southern part of the Western Ghats is separated from the main Sahyadri range by Palghat Gap which presents a sudden break in the continuity of this mountain range. The high ranges terminate abruptly on either side of this gap. This 24-30 km. wide gap has an elevation ranging from 75 to 300m. while the bordering hills rise to 1500-2000 m. above mean sea level. This gap is used by a number of roads and railway lines to connect the plains of Tamil Nadu with the coastal plain of Kerala. South of the Palghat Gap there is an intricate system of steep and rugged slopes on both the eastern and western sides of the ghats. Anai Mudi (2,695 m.) is the highest peak in the whole of southern India. This is a nodal point from which three ranges radiate in different directions. These ranges are the Annamalai (1800-2000 m.) to the north, the Paini (900-1200 m.) to the north-east and the Cardamom Hills or the *Ealaimalai* to the south.

5. The Eastern Ghats

Bordering the eastern edge of the Deccan Plateau, the Eastern Ghats run almost parallel to the east coast of India leaving broad plains between their base and the coast. In striking contrast to the continuous eminence of the Western Ghats, it is a chain of highly broken and detached hills starting from the

Mahanadi in Orissa to the Vagai in Tamil Nadu. The hills constituting the Eastern Ghats have neither the structural unity nor physiographic continuity. In fact, they almost disappear between the Godaveri and the Krishna. The name Eastern Ghats is, therefore, something of a misnomer and various mountains and hill groups are generally treated as independent units. In view of the haterogenous character, Spate has preferred to use the terms *Eastern Hills* for the northern, Cuddapah Ranges for the central and *Tamilnadu Hills* for the southern groups in place of the collective term of Eastern Ghats. Still many geographers tend to use the term Eastern Ghats to this discontinuous linear assemblage of hills, each group of hills having its separate identity.

Depending upon the relief and structure, the Eastern Ghats can be divided into northern and southern parts, the dividing boundary lying somewhere south of the Godavari valley. It is only in the northern part, between the Mahanadi and the Godavari, that the Eastern Ghats exhibit true mountain character with a width of 200 km in the north and 100 km. in the south. This part comprises the Maliya and the Madugula Konda ranges. The peaks and ridges of the Maliya range have a general elevation of 900-1200 m. and Mahendra Giri (1501 m.) is the tallest peak here. The Madugula Konda range has higher elevations ranging from 1,100 m. & 1,400 m. with several peaks exceeding 1,600 m. Anna Konda (1680 m.) Gali Konda (1,643 m.) and Sinkram Gutta (1,620 m.) are important peaks.

Between the Godavari and the Krishna rivers the Eastern Ghais lose their hilly character and the saddle between these two rivers is occupied by Gondwana formations. The Eastern Ghats reappeared as more or less a continuous hill range in Cuddapah and Kurnool districts of Andhra Pradesh. Here, the arcuate Nallamalai Range with general elevation of 600-850 m. is the most prominent. It is composed of quartze and slate The southern part of this range is called the Palkodna range. To the south, the hills and plateaus attain very low altitudes; only Javadi Hills and the Shevroy-Kalrayan Hills form two distinct features of 1000 m-elevation. The Biligiri Rangan Hills in Coimbatore district attain a height of 1279 m. These hills have steep slope and bold relief because they are made of charnockites.

Further south, the Eastern Ghats merge with the Western Ghats.

SIGNIFICANCE OF THE PENINSULAR PIATEAU

The Peninsular Plateau of India is the oldest and the most stable landmass of the Indian sub-continent. It contains a rich variety of minerals which occur in large quantities. There are huge deposits of iron, manganese, copper, bauxite chromium, mica, gold, etc. Above all, 98 percent of the Gondwana coal deposits of India are found in the Peninsular Plateau. Besides there are large reserves of slate, shale, sandstones and marbles. etc. A large part of north-west plateau is covered with fertile black lava soil which is extremely useful for growing cotton. Some other areas of the Peninsular plateau are suitable for the cultivation of tea, coffee rubber, millets, spices tobacco and oilseeds. Some low lying areas of the plateau are suitable for growing rice. A variety of tropical fruits is also grown here. The highlands of the plateau are covered with different types of forests which provide a large variety of forest products. The rivers originating in the western ghats offer great opportunity for developing hydroelectricity and providing irrigation facilities to the agricultural crops. The plateau is also known for its hill resorts such as Udagamangalam (Ooty), Panchmarhi, Kodaikanal, Mahabaleshwar, Khandala, Matheron, Mount Abu.

THE COASTAL PLAINS

The narrow coastal strip between the edges of the Peninsular Plateau and the coastline of India running for a distance of about six thousand kilometres from the Rann of Kachchh in the west to the Ganga-Brahmaputra delta in the east is called the coastal plains. The area between the Western Ghats and the Arabian See coast is known as the West Coastal Plain and that between the Eastern Ghats and the Coast of the Bay of Bengal is called the East Coastal Plains. The two coastal plains meet each other at the southernmost tip *i.e.,* Kanniyakumari.

THE WEST COASTAL PLAINS

Stretching from Rann of Kachchh in the north to Kanniyakumari in the South, there are narrow west coastal plains with an average width of about 65 km. It is quite narrow in the middle and a bit broader in the northern and southern parts. Depending upon relief and structure, it can be divided into following subdivisions.

The Kuchchh Peninsula was an island surrounded by seas and lagoons. These seas and lagoons were later filled by sediment brought by the Indus river which used to flow through this area. Thus the island became a part of the mainland and comparatively broad plain was formed. Some scholars do not consider it as part of the west coastal plains and treat it as a separate identity. There are other geographers who consider Kachchh and Kathiawar as part of the Peninsular plateau because Kathiawar is made of the Deccan Lava and there are tertiary rocks in the Kuchchh area. The true west coastal plains, according to them, lies between Surat and Kanya Kumari for a distance of 1600 kms. But the ground reality is that it is, more or less, a plain area and lies near the west coast of India. Hence it should be treated as an integral part of the West Coastal Plains.

Due to scarcity of rain an flowing surface water, the work of wind is felt everywhere and this has given rise to arid and semi-arid landscape. Coastal sand dunes, sandy plains, interrupted with bare rocky hills are the chief characteristics physiographic features.

All along the north of Kuchchh there lies a broad level salt-soaked plain. This is the *Great Rann*. Its southern continuation, known as the *Little Rann* lies on the coast and south-east of Kuchchh. The flat and unbroken Great Rann is about 320 km. long with a maximum width of 160 km., covering an area of about 21,500 sq. km. It rises only a few metres above the sea level and is flooded by the Banas and the Luni rivers during the rainy season. Some places are actually below sea level and are inundated during high tides. Most of the area is formed of sun-baked dark silt encrusted with salt. A few patches of high ground are covered with grass and break the monotony of the otherwise flat plain.

The Kathiawar Peninsula lies to the south of the Kuchchh. It is encircled on the east and north-east by the Little Rann and the Nal Basin: The average elevation is less than 200 m. The central part is a highland of Mandav Hills from which small streams radiate in all directions. Mt. Girnar (1,117 m.), the highest point, is supposed to be of volcanic origin. The Gir Range is located in the southern part of the Kathiawar, peninsula. It is covered with dense forests and is famous as the home of Gir lion.

The Gujarat Plain lying east of Kuchchh and Kathiawar slopes towards the west and south west. It may almost be described as an intrusion of Indo-Gangtic conditions into the Peninsula. Formed by the rivers *Narmada, Tapi, Mahi* and *Sabarmati* actively prograding into the Gulf of Khambhat, the plain includes the southern part of Gujarat and the coastal areas of the Gulf of Khambhat. This is a low plain no part of which exceeds 150 m. elevation. The eastern part of this plain is made of sediments and is fertile enough to support agriculture, but the greater part near the coast is covered by wind blown loss which has given rise to semi-arid landscape. A chain of saline marshes near the coast is prone to floods during high tide.

The Konkan Plain south of the Gujarat plain extends from Daman to Goa for a distance of about 500 km. with its width varying from 50 to 80 km. It has some features of marine erosion including cliffs, shoals, reefs and islands in the Arabian Sea. Mumbai was an island but parts of the sea lying between the mainland and the island have been reclaimed in recent years to connect it with the mainland. The Thane creek of the Ulhas around the Mumbai island is an important embayment which provides an excellent natural harbour on the southern side of the island. South of Mumbai, the Konkan coast has a series of small bays and coves lying between jutting head- lands and containing beaches of sand. Behind the alluvial coastal belt, there is a series of parallel ridges reaching 450-600 m. in which rivers like the Vaitarni, Ulhas and Amba have lower courses more or less parallel to the coast before reaching it transversely. Some lateratic hillocks rise to 100m. above mean sea level.

The Karnataka Coastal Plain from Goa to Mangalore is about 225 km. long. It is a narrow plain with an average width of 30-50 km., the maximum being 70 km. near Mangalore. The central part of this plain between Cape Ramas in Goa and Coondapoor is crossed by numerous spurs projecting from the Ghats. These spurs approach so close to the coast that the breadth of the lowland is reduced to 5-7 km. at 14°N latitude where the Gnat's crest is only 13 km. away from the sea. Running like ridges, the spurs attain heights more than 600 m. near the Ghats. At some places the streams originating in the Western Ghats descend along steep slope and make waterfalls. The Sharavati while descending over such a steep slope makes an impressive waterfall known as *Gersoppa* (*Jog*) Fall which is 271 m. high. Marine topography is quite marked on the coast.

The Kerala Plain also known as the *Malabar Plain*, between Mangalore and Kanniyakumari is about 500 km. long. This is much wider than the Karnataka plain and at places it is 96 km. wide. It is a low lying plain and at no place its height exceeds 30 m. The existence of lakes, lagoons, backwaters, spits, etc. is a significant characteristic of the Kerala coast. The backwaters, locally known as kayals axe the shallow lagoons or inlets of the sea, lying parallel to the coastline. The largest among these is the Vembanad lake which is about 75 km. long and 5-10 km. wide and gives rise to a 55 km long spit. Kochi is situated on its opening into the sea. This and several other lagoons have been joined together by canals to provide excellent inland waterways from the mouth of the Ponnani to Thiruvananthapuram.

THE EAST COASTAL PLAINS

Between the Eastern Ghats and the east coast of India are located the East Coastal Plains extending from the Subarnarekha river along the West Bengal-Orissa border to Kanniyakumari. A major part of the plains is formed as a result of the alluvial fillings of the tiltoral zone by the rivers Mahanadi, Godavari, Krishna and Cauvery comprising some of the largest deltas. Its western boundary is a discontinuous line of the Eastern Ghats, more precisely by the contours of 75 m. in Orissa, 100 m. in Andhra Pradesh and 150 m. in Tamil Nadu. In contrast to the West Coastal Plains, these are extensive plains with an average width of 120 km. although, it may be as wide as 200 km. in the deltaic regions and as narrow as 35 km. in-between the deltas. This plain is known as the Northern Circars between the Mahanadi and the Krishna rivers and Carnatic between the Krishna and the Cauvery rivers. Depending upon physiographic variations, the entire plain is divided into three regions.

The Utkal Plain comprising coastal areas of Orissa is about 400 km. long. It includes the Mahanadi delta with Cuttack at its head. There is thick layer of alluvium covering this delta. The most prominent physiographic feature of this plain is the Chilka Lake in the south of the Mahanadi delta. This lagoon on the Orissa coast is about 70 km. long and its maximum width on the north-east is nearly 22 km. narrowing to about 7 km. on its south-western end. It is the biggest lake in the country and its area varies between 780 sq. km. in winter to 1,144 sq. km. in the monsoon months. South of Chilka Lake, low hills dot the plain.

The Andhra Plain lies south of the Utkal Plain and extends upto Pulicat Lake, some 40 km. north of Chennai. This lake JIBS been barred by long sand spit known as Sriharikota Island, on which is located the satellite launching station of the Indian Space Research Organisation. The lagoon is about 60 km. long and about 16 km. wide in its widest part. The most significant feature of this plain is the delta formation by the rivers Godavari and Krishna.

In fact, the two deltas have merged with each other and formed a single physiographic unit. The combined delta advanced by about 35 km. towards the sea during the recent years. This is clear from the present location of the Kolleru lake which was once a lagoon at the shore but now lies far inland. This part of the Andhra plain is quite wide. Andhra plain has straight coast and badly lacks good harbours with the exception of Vishakhapatnam and Machilipatnam.

The Tamil Nadu Plain stretches for 675 km. from Pulicul lake to Kanniyakumari along the coast of Tamil Nadu. Its average width is 100 km. The most important feature of this plain is the Cauvery delta where the plain is 130 km. wide. The fertile soil and large scale irrigation facilities have made the Cauvery delta the *granary of South India*

SIGNIFICANCE OF THE COASTAL PLAINS

Large parts of the coastal plains of India are covered by fertile soils on which different crops are grown. Rice is the main crop of these areas. Coconut trees grow all along the coast. The entire length of the coast is dotted with big and small ports which help in carrying out trade. About 98% of our international trade is carried through these ports. The sedimentary rocks of these plains are said to contain large deposits of mineral oil. The sands of Kerala coast have large quantity of monazite which is used for nuclear power. Fishing is an important occupation of the people living in the coastal areas. Low lying areas of Gujarat are famous for producing salt.

INTRODUCTION TO GEOLOGY

The geological structure, which includes the arrangement and deposition of rocks in the earth's crust, plays a dominant role in determining the relief of land and nature of soil. It also helps in knowing about the vast mineral wealth buried beneath the earth's surface. Therefore, it is necessary for us to study the geology of India before we proceed to learn more about the geography of the country.

Geologically, India is divided into three regions, viz.:

(1) *the Peninsular region*, including the Meghalaya plateau in the north-east and the Kuchchh-Kathiawar region in the west;

(2) *the extra-peninsular region*—the Himalayas and their eastern extensions including Andaman and Nicobar Islands, and

(3) *the Indo-Gangetic plain*, between Peninsular and extra-peninsular region.

Although, the *triple tectonic division* of India as mentioned above is generally held valid and is readily accepted by majority of geologists, some scholars recognise only two geological divisions of India *i.e.* the *Peninsular* block and the *Extra-*

Peninsular region comprising the Himalayan ranges and the Indo-Gangetic plain. These macro-regions present most striking geological contrasts. The Peninsula is one of the oldest land-masses of the earth and is dominated by open senile topography. The Extra-Peninsula, on the other hand, presents the most youthful relief of the earth in the form of the Himalayas. The alluvial filled Indo-Gangetic plain presents flat, featureless and monotonous topography. The Indian Peninsula has not undergone marine submergence since the *Cambrian period* and is not much affected by the tectonic forces. In contrast, the extra-peninsular region has its origin in the Tethys Sea and is prone to tectonic forces resulting in devastating earthquakes. It is a weak and flexible portion of the earth's crust which has been folded, faulted and overthrust.

Geologically India represents a monumental assemblage of rocks of different characters belonging to different ages, ranging from pre-Cambrian (prior to 600 million years) to the recent times. The Geological Survey of India has classified the rock systems of the country into following four major divisions:

1. The Archaean Rock System
2. The Purana Rock System
3. The Dravidian Rock System
4. The Aryan Rock System.

THE ARCHAEAN ROCK SYSTEM

The word 'Archaean' was first used by J.D. Dana for rock structure prior to the Cambrian system. Obviously the Archaean rocks are the oldest in the world. The Archaean rock system includes the following rock groups:

(a) The Archaean System-Gneisses and Schists

These are the oldest rocks and were the first to be formed at the time of cooling and solidification of the upper crust to the earth's surface in the pre-Cambrian era (about 4000 million years ago). Although, their broad characteristics are well known, the details of their origin continue to arise considerable speculation. They are all azoic, thoroughly crystalline, extremely contorted and faulted, often formed as plutonic intrusions and generally have a well defined foliated structure. They often underlie strata formed subsequently and the system is generally known by names of the '*Fundamental Complex*' or the '*Basement Complex*'. Their details are complex but recent advances in geochemistry are likely to enhance our under- standing of their formation.

The most common Archaean rock covering about two-thirds of the Peninsular surface is the gneiss. This is the rock which in mineral composition may vary from granite to gabro, possesses a constant, more or less foliated or banded structure. The schists, mostly crystalline, include mica, talc, hornblende, chlorite, epidote sillimanite and graphite schists.

The crystalline metamorphosed sediments and gneissic rocks cover large parts of India. The central and the southern parts of the Peninsula are occupied by this rock system. To the north-east of the Peninsula, they occupy wide areas in Orissa, Meghalaya. Madhya Pradesh, and Chotanagpur plateau of Bihar. They also cover the whole of Bundelkhand in the north and to the north-west, they are found in a number of isolated outcrops, extending from north of Vadodara to a long distance along the Aravalis. In the extra-peninsula, these rocks are exposed all along the Himalayas, farming the bulk of the high ranges and the backbone of the mountain system.

(b) The Dharwar System

This system derives its name from the rocks first studied in the Dharwar district of Karnataka where such rocks are found in abundance. The Dharwars include some of the highly metamorphosed rocks of both sedimentary and igneous origin. According to Wadia, the Dharwar Systems are the most ancient metamorphosed sedimentary rock-systems of India, as old as, and in some cases older than, the basement gneisses and schists. He further adds that the weathering of the pristine Archaean gneisses and schists yielded the earliest sediments which were deposited on the bed of the sea, and formed the oldest sedimentary strata, known in the geology of India as the Dharwar System. Some of the metamorphosed rocks of the igneous origin are also included in this system. Most rocks of the Dharwar system are so metamorphosed that they are practically indistinguishable from their primitive formations. The major rocks of the Dharwar system are hornblende, schists, quartzites, phyllites, slates, crystalline limestones and dolomites. These rocks were deposited in three major cycles, the earliest one is over 3,100 million years old and the latest one about 2,300 million years. They were metamorphosed around 1,000 million years ago.

The Dharwar system is very well developed in the Dharwar-Bellary-Mysore belt of Karnataka. It also occurs in Bihar (Ranchi, Gaya, Hazaribagh), Madhya Pradesh (Bastar, Balaghat, Rewa), Orissa (Sundergarh, Keonjhar) and in the Aravalis between Jaipur and Palanpur. In the extra-Peninsular region, the Dharwar system is well represented in the Himalayas both in the central and northern zones as well as in the Meghalaya plateau.

The Dharwars are economically the most important rocks because they possess valuable minerals like high grade iron-ore, manganese, copper, lead, gold, quartzites, slates, mica, etc.

THE PURANA ROCK SYSTEM (1400-600 MILLION YEARS)

In India, the word purana has been used in place of Proterozoic and includes two divisions: the Cuddapah System and the Vindhyas.

The Cuddapah System

A long interval of time elapsed before the rock system next to the Dharwars and Peninsular gneisses began to be deposited. A great thickness of unfossiliferous clay, slates, quartzites, sandstones and limestones was deposited presumably in great synclinal basins. This formation is known as the Cuddapah system, from the occurrence of the most typical and first-studied, outcrops of these rocks in Cuddapah district of Andhra Pradesh. Naturally, the Cuddapah system is separated from the Dharwar system by a great unconformity. In some parts of southern India, we have the Cuddapah system amounting to 6,100 metres in thickness with several unconformities.

The most extensive occurrence of this system is in the Cuddapah district followed by the Kurnool district of Andhra Pradesh. The outcrop is of an irregular crescent shape concave towards the coast covering an area of about 45,000 sq. km. The crescent shaped outcrops of the Cuddapah rocks suggest that the rocks were subjected to compressive forces directed from the concave side near which stood high mountains that supplied materials forming the rocks of the basin. Another large development of this system is in the Chhattisgarh area of Madhya Pradesh. A few isolated exposures occur in Singhbhum district of Bihar, Kalahandi and Keonjhar districts of Orissa and along the main axis of the Aravalli range from Delhi to Idar in Gujarat aggregating 5200 metres in thickness at certain places.

The economic significance of the Cuddapah system lies in the fact that these rocks contain ores of iron, manganese, copper, cobalt, and nickel, barytes, jasper, asbestos, steatite and cherts. They also contain large deposits of building purpose quartzites and cement grade limestones.

The Vindhyan System (1300-600 million years).

This system derives its name from the great Vindhyan mountains although Spate has tried to distinguish between the Vindhyan rocks and the Vindhyan hills. The system comprises of ancient sedimentary rocks superimposed on the Archaean base. It is a vast stratified formation of sandstones, shales and limestones, often over 4000 m. thick. Except a few traces of animal and vegetable life, this group is devoid of any recognisable fossils. Occupying a large area of over 1,00,000 sq. km., the Vindhyan system stretches from Sasaram and Rohtas in western Bihar to Chittaurgarh in Rajasthan with the exception of a central tract in Bundelkhand which makes a gap in this belt. Large area of this belt is covered by the Deccan trap. The outcrop has the maximum breadth between Agra and Neemuch. They are also found in Chhattisgarh area of Madhya Pradesh, Bhima Valley of Karnataka and Kurnool district of Andhra Pradesh. The Vindhyans have been found to continue to the north under the Gangetic alluvium and they are perhaps buckled down underneath the Himalaya. The rocks of the Vindhyan system comprise two distinct but unequal sets of deposits. The *Lower Vindhyan* (1,300-1,100 million years) is marine in origin, mostly calcareaus in nature and shows tectonic deformation by folding movements. This system is well placed in the Son valley, in Chhattisgarh, in the valley of the Bhima and in a separate basin in Mewar. The *upper Vindhayan system* (1000-600 million years), on the other hand, is fluviatile in origin and is gently lying in undisturbed horizontal strata. The Lower and the Upper Vindhyans are separated by an unconformity which is quite prominent in the north but almost disappears in south areas of Mewar, Chittaurgarh and the Son valley.

The Upper Vindhayan beds enclose two diamond bearing horizons, from which Panna and Golconda diamonds have been mined. The Vindhyan system, on the whole, is devoid of metalliferous minerals but provides large quantities of excellent and durable free stones, flagstones, ornamental stones, limestone, pure glass making sand and some coal.

THE DRAVIDIAN ROCK SYSTEM (PALAEOZOIC)

The rocks of the Dravidian system came into being about 600-300 million years ago. Most rocks of this system are found in the Extra Peninsular region and they are conspicuous by their absence in the Peninsular India except for one or two small patches of lower Permian age near Umaria. The Cambrian and Devonian rocks containing recognisable fossils are unknown in the Peninsula. The rocks belonging to the Dravidian System contain abundant fossils which help in determining correctly the age of the rocks and make correlation of rocks possible over distant areas. The rocks of Cambrian, Ordovician, Silurian, Devonian and Carboniferous periods are included in the Dravidian system.

The Cambrian rucks (600 Million Years) named after Cambria the Latin name for Wales in Great Britain, include slates, clays, quartzites and limestones. They are best developed in the north west Himalayan region. In the Spiti valley of Himachal Pradesh, there is an extensive fauna known as the *Haimanta System.* This 1600 metre thick deposit consists of slates, quartzites and dolomites. Similar formations are found north of Kullu and Lahul in Himachal Pradesh as well as in the Baramula district of Jammu and Kashmir. In Kumaon, some slaty and sandy rocks of the Cambrian period are found. In the salt range on the Indo-Pak border, the Cambrian is represented by 900 metres of fossiliferous sandstones, shales and dolomites underlain by salt marl (clayey salt) known as the saline series.

The Ordovician rocks after the Ordovices, former inhabitants of Wales (500 million years) include quartzites, grits, sandstones and limestones. They overlie the Haimanta system in all parts of the Spiti in the form of a thick series underlain by conglomerates. They are also present in the Lidar valley of Kashmir and in the Kumaon region.

The Silurian rocks after the Silures, former inhabitants on the borders of Wales and England (440 million years). In the Spiti valley, the Siberian rocks are in continuation with the Ordovicians containing such characteristics brachiopods as Pentamerus oblongus and chain coral. Round the core of the Lidar anticline there runs a thin but continuous band of Silurian strata. The Lahul and the Kullu valleys of Himachal Pradesh also have some Silurian deposits. The limes and shales of the Kumaon region belong to the Silurian period.

The Devonian rocks after Devonshire in England (400 million years) are a great thickness of massive white quartzite reaching a thickness of 900 m. at certain places. They are devoid of any fossil remains. These rocks have definitely been identified in the Muth quartzite of Spiti and Kumaon, on the flanks of Lidar anticline, in the Haridwar district.

The Carboniferous rocks (350 million years) comprise mainly of limestone, shale and quartzite. These rocks are generally divided into the *Upper Carboniferous, Middle Carboniferous and Lower Carboniferous systems. The Upper Carboniferous* rocks are made of limestone and dolomite. Mount Everest is composed of Upper *Carboniferous* limestones. The Middle *Carboniferous* has been the age of great upheavels. The rocks of this group are mainly found in the Spiti valley, Kashmir, Shimla and in the eastern Himalayas. In the Lower *Carboniferous* group are included slates of different types, Pir Panjal trap, and some rocks of the Kumaon region. Coal formation started in the Carboniferous age. Carboniferous in Geology means coal bearing.

THE ARYAN ROCK SYSTEM

The Aryan System comprises the rock formations ranging from the *Upper Carboniferous to Recent*. They are fairly preserved in the Peninsular India and are found in a perfect sequence in the Himalayan region along the entire northern border.

The Gondwana System derives its name from the Kingdom of the Gonds, the most primitive people living in Andhra Pradesh. It has relevance with the Gond region of Madhya Pradesh also where these rocks were first discovered. The Gondwanas consist of sandstones with some shales and clays. They are of continental origin, fluviatile and lacustrine deposits laid down in geosynclinal troughs on ancient plateau surface. As the sediments accumulated, the loaded troughs subsided which led to thick deposits of fresh water and subaerial sediments into which were embedded the terrestrial plants and animals. These flat Sedimentary strata, some 6000 m. thick, were laid down from the start of the Permian period some 250 million years ago. The system shows several climatic changes during its deposition.

There are three main areas of Gondwana rocks in the Peninsula; along the Damodar Valley, in Madhya Pradesh and the Mahanadi River and a series of troughs along the Godavari from Nagpur to the delta. In the extra-peninsular region these rocks are found in Kashmir, Darjeeling and Sikkim. Here they are so much deformed that they have lost their original identity and are entirely different from the peninsular rocks'

Economically, the Gondwana series is the most important in India containing about 98 percent of her coal reserves. They have rich deposits of iron ore, copper, uranium and antinomy. Sandstones, slates and conglomerates are used as building materials.

The Triassic System meaning three fold (180-225 million years) is almost unknown in the Peninsula but are founu over extensive areas from Hazara to Nepal. Impressive sections of the system are exposed on the south flank of the Great Himalaya range from Kashmir to Byans in Eastern Kumaon. The trias are generally divided into lower, middle and upper divisions. *The Lower Trias* is over 100 m. thick in Kashmir, 50m. in Byans and only 12 m. in Spiti. *The Middle Trias* is 275 m. thick in Kashmir. *The Upper Trias* of Kashmir are 1200-1800 m. thick well bedded limestones. In the Spiti both these stages are represented by about 1,000 m. thick dominantly calcareous strata.

The Jurassic System, after Jura mountains on the borders of France and Switzerland (180 million years) overlies the Triassic, covering wide areas in Tibet, South Ladakh, Spiti, Nepal and Bhutan, where limestone occurs to a depth of 600-900 m. The marine transgression in the latter part of the Jurassic gave rise to thick series of shallow water deposits in Rajasthan and in Kachchh. There is 190 km. long and 64 km. wide area in Kuchchh which is covered by rocks of the Jurassic system. Coral limestone, oolitic limestone, sandstone, conglomerates and shales occur in Kuchchh. The Jaisalmer area of Rajasthan also has some Jurassic rocks. Another transgression on the east coast of the Peninsula between Guntur and Rajahmundry has resulted in the development of marine Upper Jurassic strata interbedded with the upper Gondwana formation.

The Cretaceous System, from Creta, the Latin name for chalk (70-135 million years), is one of the best developed marine systems of India showing a variety of faces and represented by a wide variety of rocks, deposited in the land, sea estuaries and lakes. No other system is so widely distributed in India as the Cretaceous System is, both in the Peninsular and the Extra-peninsular parts.

The Cretaceous rocks of the Spiti area include sandstones, quartzites, limestones and shales. In the Kumoun region, the important rocks are sandstones and shales. Cretaceous limestones are also found in Rupshu and Burzil areas of Kashmir. The plateau of Meghalaya has sandstones. The upper Cretaceous system occur in the Pondicherry-Tiruchirapalli belt. Some detached outcrops of marine Cretaceous, known as Bagh Beds in Gwalior are found along the Narmada Valley where they underlie the Deccan Trap. In the Central parts of the Peninsula occur estuarine and lacustrine deposits called the Lemetas.

The Deccan Trap

From the end of the Cretaceous till the beginning of the Eocene, stupendous volcanic outburst overwhelmed a vast area of the Peninsular India, like the one which is seldom known anywhere else in the world geological history. A vast area of about ten lakh sq. km. was flooded by the outpourings of extremely mobile basalt lava from fissures and cracks covering fully the pre-existing topography. These volcanic deposits have flat top and steep sides so that they appear as gigantic steps from a distance, and therefore called trap, the name derived from the Swedish word meaning a 'stair' or 'step'.

However, Spate feels that the term Deccan Traps is used in old literature and he prefers to use the term 'Deccan Lava' instead. The individual lava flows that make up the Deccan Trap plateau vary greatly from a fraction of a metre to 36 metres in thickness. The hills formed by them are in some places over 1200 metre high. It is estimated that the molten rock of the order of 6.5 million cubic metres, exceeding the bulk of the entire Himalaya, was poured out from the interior of the earth to form this volcanic plateau over 1800 m. in height.

The process of denudation over a long period has reduced the Deccan Trap to almost half of its original size and the present Deccan Trap covers about 5 lakh sq. km. mainly in parts of Kuchchh, Saurashtra, Maharashtra, the Malwa plateau and northern Karnataka. Parts of Andhra, Tamilnadu, Bihar and Uttar Pradesh also have some outliers of the Deccan Trap. The thickness of the Deccan Traps is not uniform everywhere. It is as much as 3,000 meters along the coast of Mumbai which is reduced to 600-800 metres towards the southern limit, 800 metres in Kuchchh and only 150 metres at Amarkantak near its eastern limit. The Deccan Traps have been divided into following groups.

(a) The Upper Traps, found in Maharashtra and Saurashtra have numerous inter-trappean beds and layers of volcanic ash and have an average thickness of about 450m.

(b) The Middle Traps are about 1200 m. thick and are spread over. Central India and Malwa. They have numerous ash-beds in the upper portion and are practically devoid of inter-trappeans.

(c) The Lower Traps are only 150 m. thick with inter trappean beds but rare ash beds. They are found in Central India and Tamil Nadu.

Basalt is the main rock but dolorite, rhyolite, gabro and many other rocks are also found. These rocks are a great source of quartz, agate, calcite, building stones and road building material. The weathering of these rocks for a long time has given birth to black cotton soil known as '*regur*'.

The Tertiary System

The rocks of the Tertiary System were formed from Eocene to Pliocene about 60 to 7 million years ago. The tertiary is the most significant period in India's geological history because the Himalayas were born and India's present form came into being in this period. The Tertiary has been called the *Age of the Mammals* because of the abundance of the fossil remains of these animals in the deposits of this period. The Tertiary System is generally divided into the following three systems.

(a) *The Eocene System* (60 million years ago) is mainly found in Jammu and Kashmir, Himachal Pradesh, Rajasthan, Gujarat and in the north-eastern part of India.. The Eocene belt of Jammu goes upto Shimla and further east upto Mussoorie. Such deposits also occur in the southern flank of the Pir Panjal. In Rajasthan, the lignite deposits belong to the Eocene System. The Kuchchh, Surat and Baroach areas of Gujarat have deposits of the Eocene System. In the north eastern parts of the country, the Eocene is represented by limestones and coal-bearing sandstones in Jaintia series in the southern and eastern parts of the Meghalaya plateau. The Barail series have a wide distribution .in Surma Valley and in the Naga Hills. The Tertiary coal deposits of Upper Assam are worth noting. Some Eocene deposits have recently been noticed in Pondicherry.

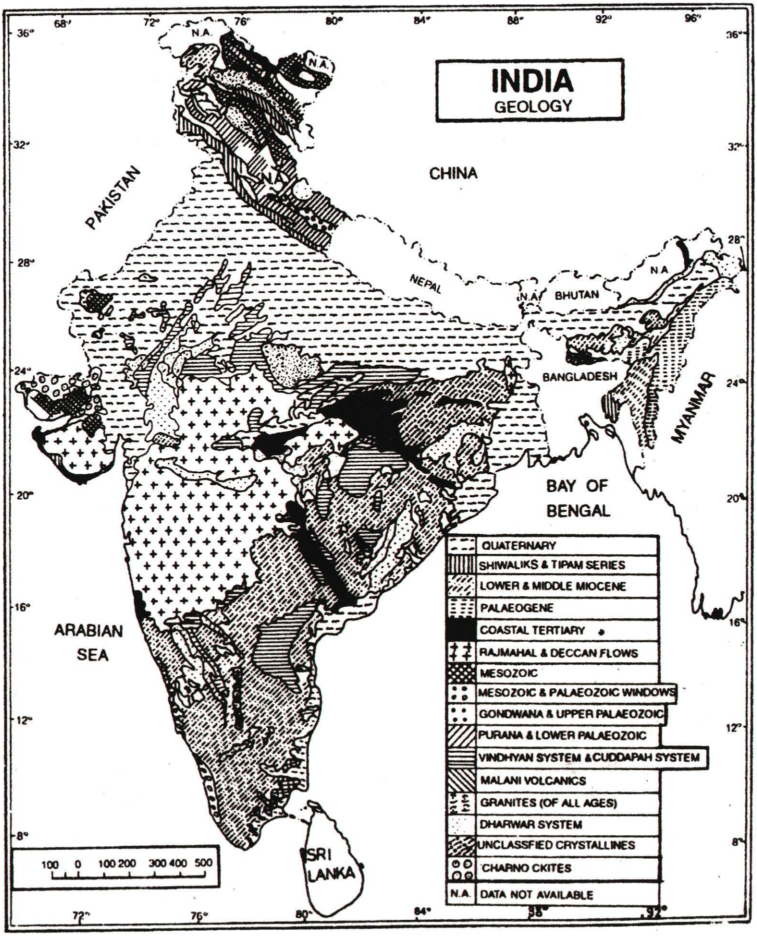
INDIA
GEOLOGY
CHINA
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
MYANMAR
BAY OF BENGAL
ARABIAN SEA
SRI LANKA
N.A.
QUATERNARY
SHIWALIKS & TIPAM SERIES
LOWER & MIDDLE MIOCENE
PALAEOGENE
COASTAL TERTIARY
RAJMAHAL & DECCAN FLOWS
MESOZOIC
MESOZOIC & PALAEOZOIC WINDOWS
GONDWANA & UPPER PALAEOZOIC
PURANA & LOWER PALAEOZOIC
VINDHYAN SYSTEM & CUDDAPAH SYSTEM
MALANI VOLCANICS
GRANITES (OF ALL AGES)
DHARWAR SYSTEM
UNCLASSFIED CRYSTALLINES
CHARNO CKITES
N.A. DATA NOT AVAILABLE
100 0 100 200 300 400 500
68° 72° 76° 80° 84° 88° 92° 96°
36° 32° 28° 24° 20° 16° 12° 8°

Fig. 5.11 : India—Geology.

(b) *Oligocene and Lower Miocene System* (25-40 million years) is very poorly developed in India. It is estimated that during a part of this period the Tertiary outcrops suffered a considerable denudation which resulted in the removal of rocks belonging to this system. Rocks of the Oligocene age are found in the greater part of the

Barail series of Assam where they are overlain with marked unconformity by Lower Miocene rocks.

Unlike the Oligocene, the Miocene system is fully developed in India and is found in all the Tertiary areas of the extra-Peninsula. The outcrop of the Murree series in Jammu hills, forming a belt of 25-40 km. wide from the Indus to the Chenab, narrows towards the east and merges into the typical Dagshai-Kasauli band (Sirmur series) is of Shimla area.

The thickness of the deposits in Dagshai-Kasauli band is about 2600 m. and is dominated by red clay and sandstone. No major fossils are seen in Dagshai and Kasauli group. The coal measures of Assam, belonging to the Barail series are overlain by the Surma series. It is composed of sandstones and sandy shales, mudstones and conglomerates. The deposits of Garo Hills have large number of marine fossils. Besides some rocks of Kuchchh in Gujarat, Mayurbhanj in Orissa, Durgapur in West Bengal, and Kollam in Kerala also belong to this group.

The Shiwalik System—Middle Miocene to Lower Pleistocene (200,000 to 14,000,000 years ago) takes its name from Shiwalik hills between rivers Ganga and Yamuna, where they were first known to science. It is from here the first palaeontological treasures were obtained which have made this system extremely famous with the geologists all over the world.

The Shiwalik strata are found all along the length of the Shiwalik hills, Sandstones, grits, conglomerates, clays, and silts comprise the rocks of this system. They have been deposited in lagoons and fresh water lakes by the rivers of that time upto a thickness of about 5000 m. The great bulk of the Shiwalik formation is unfossiliferous, but in certain areas some formations are richly fossiliferous. The fauna records the sedimentation from Middle Miocene to Lower Pleistocene and has yielded a variety of fossils showing wide range of environment—from humid forest conditions to aridily. The mammalian fossils were first discovered from the Shiwaliks near Haridwarin 1839.

The Shiwalik strata are divided into the following three sections, the passage from one into the other division being quite gradual and transitional.

Table 5.1 : Division of Shiwalik Strata

Upper Shiwaliks 1800.2750m.	Boulder Conglomerate Beds, Sandstones, thick earthy clays. Richly fossiliferous in Shiwalik hills	Lower Pleistocene to Upper and Lower Pliocene
Middle Shiwaliks 1800.2500m.	Gravels, sandstones, shales and clays	Upper to Middle Miocene
Lower Shiwaliks 1200-1500m.	Bright red shales and Sandstones	Middle Miocene

In Assam the Shiwalik system is almost equivalent to the Tipam, Dupi Tila and Dihing series. In the southern part of Assam the lower part of the Tipam series consists of coarse ferruginous sandstones and sandy shales, and has some marine fossils. Above the Tipam series lies the Dupi Tila series which consists of sandstone and conglomerates. Its lower beds contain the oil fields of Lakhimpur and Digboi. The Dihing beds overlie the Dupi Tila and corresponds to the Upper Shiwaliks.

The Shiwalik rocks are also found in Kuchchh and Saurashtra areas of Gujarat. Highly fossiliferous beds have struck in a well at Karikal on the Thanjavur coast (Tamil Nadu). In Mayurbhanj area of Orissa there are rocks of Miocene age. Some rocks of Middle Miocene and Lower Pleistocene age are seen in Varkala (Kerala) as well as in the sandstones of Cuddalore and Rajahmundry.

The Shiwalik system is famous for its oil resources, lignite, bauxite and clays of different varieties.

The Pleistocene and Recent (Quaternary) is a brief period of nearly one million years and is said to have just begun. It has two divisions without a clear-cut boundary between them. The older is the Pleistocene which is marked by cold climate and glaciation. The younger division is called Recent. It started about 12,000 years ago since the withdrawal of the last glaciation. The Pleistocene age has been marked by several advances and retreats of the glaciers. This age is divided into four glacial and three inter-glacial periods by de Terra and Paterson. During the glacial periods, sea level was lowered by about 100 metres than it is now and this resulted in much larger extension of land.

The Himalayan glaciers were much larger during the glacial period than their present size. They have left indelible impression on the Himalayan topography. The first Glacial and Inter-glacial periods belong to the lower Pleistocene in Kashmir. The Second Glacial and Inter-glacial periods embrace Middle Pleistocene.

Heavy deposition of sediment consisting of boulder fans and thick fluvo-glacial material took place in this period. The Karewas of Kashmir are supposed to be of the second inter-glacial period. The Hat-topped terraces of the Kashmir valley, and on the flanks of the Pir Panjal consisting of clays, sands, silts together with lenticles of conglomerate from old deltaic fans are known as Karewas in Kashmiri language.

The alluvial deposits of Narmada are also of the same period. The Upper Pleistocene includes the Third and the fourth glaciations and the intervening Third Inter-Glacial period. Pir Panjal was uplifted during the First and the Third Glacial periods, and the terrace deposits of Kashmir occurred at the end of the Fourth Glaciation.

The ossiferous clays, sands and gravels of the Upper Satluj and the alluvial deposits in the valleys of Tapi, Godavari and Krishna are also of the Pleistocene age.

The most important, extensive and recent deposits in India are the Indo-Gangetic alluviums filling the great depression between the foot of the Himalayas and the northern edge of the Peninsula. The older alluvium called *bhangar* is of the *Middle* or *Upper Pleistocene age*. The newer alluvium occupies the lower areas of the river valleys prone to annual floods is called *khadar* and belongs to the Upper Pleistocene age.

THE COASTLINE OF INDIA

India has about 6100 km. long coast most of which is more or less uniform and regular with a few creeks, inlets, back waters and promonotories here and there. As such the coast of India does not offer many sites for good natural harbours. The peninsular shape of South India has divided the entire coast into western and eastern parts with Kanniyakumari at the southernmost tip as the dividing point. The Bay of Bengal and the Arabian Sea came into being during the Cretaceous or early Tertiary period after the disintegration of *Gondwanaland.*

The east coast of India extends from the Ganga delta to Kanniyakumari facing the Bay of Bengal. It is marked by deltas of great rivers like the Mahanadi, the Godavari, the Krishna and the Cauvery. There are several lagoons of which the Chilka lake and the Pulicut lagoon are outstanding.

The West Coast runs almost straight in the north-south direction right from the Gujarat plains to Kanniyakumari. However, it is dotted with a large number of coves, creeks and a few estuaries The estuaries, of the Narmada and the Tapi are well known. The Malabar coast in the south has some lakes, lagoons and backwaters, the largest being the Vembanad Lake.

There are evidences to show that large parts of Indian coast have undergone submergence and emergence during the geological times and even during the historical times. The most outstanding example of submergence of the sea coast is the existence of a submerged forest on the eastern side of the island of Mumbai. It is located at depths 6-12 m. below the present sea level where a number of tree-stumps are seen with their roots *in situ* embedded in the old soil. The submergence is further proved by the raised terraces formed of coral reefs or loosely cemented fragmentary shell limestone rocks. A similar submerged forest or old land surface, about half an acre, is seen on the Tinnevelli coast. A thick bed of lignite found at Pondicherry 73 m. below ground level also provides proof of submergence. Such vegetable debris are also found in the Ganga delta. Sudden increase in the depth of sea about 30 km. from the coast of Mekran is due to the submergence of a cliff lying at the coast. Marine archaeologists have recently discovered the ancient city of Dwarka lying under shallow waters off the coast of Saurashtra.

Examples of both submergence and emergence have been found in the Rann of Kuchchh. As a result of the great earthquake in 1819, an area of 5180 sq. km. on the western border of the Rann of Kuchchh was suddenly submerged under the sea upto a depth of 3.6 to 4.5 m. The fort of Sindree on the sea coast was completely submerged excepting a single turret which remained above the water level, Simultaneously, another area of about 1550 sq. km. was elevated by several metres. In fact there have been repeated falls in sea levels in the Rann of Kuchchh area which is evident from the presence of coastal dunes, sea cliffs in the islands of the Gulf, sea caves within the plains and raised beaches of littoral concrete on the fringes of die islands. The total fall in the sea level has been estimated at 26 m. Even during historic times the Rann of Kuchchh was a gulf which was silted up by the rivers falling into it. This process was supplemented by the slow elevation of the floor of the gulf and the entire area was converted into a low-lying tract. Before the Rann became dry, the Luni river used to enter the Arabian Sea through the Kori estuary crossing the entire length of the great Rann, and the Western Banas flowed over the Little Rann into the Gulf of Kuchchh. Some islands off the Arabian Sea coast came into existence due to submergence of low-lying areas around them. The coral archipelago of the Lakshadweep islands probably mark the site of submerged land.

Proofs of uplift of the coastal plain of Kerala are numerous and decisive. The occurrence of coral reefs below the alluvium several kilometres from the present coast and the presence of a number of lakes, lagoons or backwaters and spits are a few of them. At least two phases of uplift have been noticed.

Away from the coast in the Bay of Bengal the Andaman and Nicobar Islands were once connected with the Arakan Yoma. They have come into being as a result of submergence of the surrounding low-lying areas in the geological times. However, the shape and size of some of the islands near the Ganga delta change with the change in sea level. Old islands disappear and some new islands emerge above the sea level. The recent emergence of New Moore Island in the Ganga delta is an outstanding example of such changes.

Sri Lanka was a part of India in the Geological time and the two landmasses were connected with each other by Adam's Bridge. This link was. drowned in the Quarternary times and is now represented by Pamban Island on Indian side and the Mannar Island on the Sri Lankan side along with several other small islands lying between these two islands.

EARTHQUAKES

Earthquake is a violent tremor in the earth's crust, sending out a series of shock-waves in all directions from its place of origin. It is generally caused by sudden release of pressure along active faults and in areas of volcanic activity. The shaking and trembling of the earth's surface is associated with subterranean crustal movements.

The intensity of the earthquake is measured by Modified Mercalli Scale (MM Scale) which is expressed in Roman numerals from I to XII. An earthquake of I on MM Scale is very feable and is detected by seismograph only while an earthquake of XII on MM Scale is catastrophic. Based on intensities of the earthquakes recorded on MM Scale the Indian Standards Institution has published a map of India showing seismic zones. Map given in Figure 5.12 shows five Seismic zones based on M.M. Scale.

Zone I —Intensity V or below (Instrumental, feeble, slight, moderate, rather strong)

Zone II — Intensity VI (Strong)

Zone III — Intensity VII (Very strong)

Zone IV — Intensity VIII (Destructive)

ZoneV —Intensity IX and above (Ruinous, disastrous, very disastrous, catastrophic).

Another very popular scale which is widely used these days was devised by C.F. Richter in 1935. In has nine divisions starting from 1 to 9. The feeblest shocks have a magnitude of

3.5 and the most catastrophic could go upto the known maximum of 8.9. Damage to structures generally starts with a magnitude of 5.0 on the Richter scale.

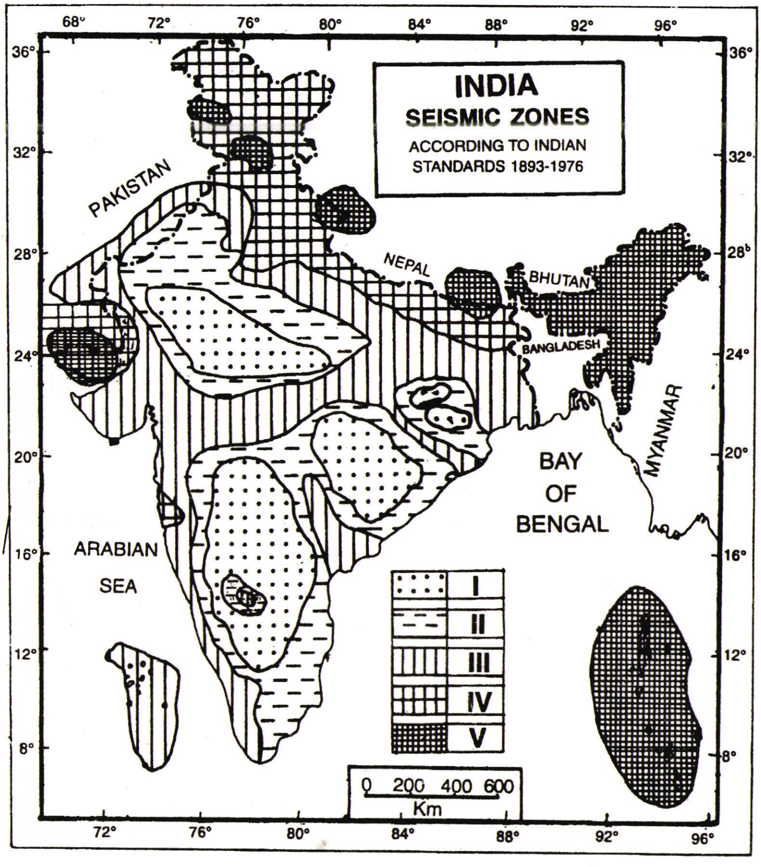
INDIA
SEISMIC ZONES
ACCORDING TO INDIAN STANDARDS 1893-1976
68°
72°
76°
80°
84°
88°
92°
96°
36°
32°
28°
24°
20°
16°
12°
8°
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
MYANMAR
BAY OF BENGAL
ARABIAN SEA
I
II
III
IV
V
0 200 400 600
Km

Fig. 5.12 : India Seismic Zones (according to Indian Standards).

According to seismologists, one part of India or the other experiences one earthquake almost everyday. But most of them are of low intensity, are harmless and go unnoticed. However, major earthquakes of higher intensity are strong enough to wreak havoc and result in great loss of life and property. Following is the list of major earthquakes, in chronological order, which rocked India since the beginning of the 19th century.

Table 5.2 : Major Earthquakes in India

Date	*Place/ Area*	*Magnitude on Richter Scale*	*Effect*
01-09-1803	Mathura	6.5	Shock was felt upto Calcutta.
16-06-1819	Kuchchh	8.0	Chief towns of Tera, Kathara and Mothala razed to the ground. Over 2,000 people died in Bhuj alone, the number of those who perished in neighbouring towns is not known.
06-06-1828	Near Srinagar	6.0	Large areas in Kashmir Valley affected. Nearly 1,000 persons were killed.
10-01-1869	Near Cachar	7.5	Felt over an area of 6,50,000 sq. km. Heavy damage to Silchar, Sylhet, Cherrapunji, Shillong, Manipur and some other towns. Earth fissures opened up on the banks of the Surma river.
30-0501885	20 km. west of Srinagar	7.0	Kamiary area destroyed. Nearly 3,000 persons died. Large fissures opened up in the ground. Extensive damage to property. Quake felt upto Shimla in Himachal and Lahore and Peshawar in Pakistan.
12-06-1885	Meghalaya Plateau	8.7	Widespread destruction in Shillong. Goalpara, Guwahati, Nawgaon and Sylhet.
14-07-1885	Bengal (40 km. north of Dhaka)	8.5	Felt over an area of 6 lakh sq. km. of West Bengal, Bangladesh, Chota Nagpur, North Bihar, Sikkim, Bhutan, Manipur and parts of Myanmar.
12-06-1897	Assam		Universal destruction of buildings in Shillong, Goalpara, Guwahati, Nowgong and Silhet spread over an area of 3.9 lakh sq. km. About 1,600 lives were lost. Tremors were felt over an area of 4.5 million sq. km. in India and neighbouring countries.

Date	*Place/ Area*	*Magnitude on Richter Scale*	*Effect*
04-04-1905	Kangra (Near Dharmshala)	8.0	About 20,000 people died. Total destruction of life and property in the Kangra valley and Dharamshala. Serious damage in Dehradun, Mussoorie, Chamba and other neighbouring towns. Slight damage upto Amritsar, Jalandhar and Saharanpur. Caused sever disturbances to streams and springs.
08-07-1918	Sriniangal (Eastern borer of Bangladesh)	7.6	Heavy damage to large areas of Assam, Bangladesh and Myannmar. Towns within a radius of 100 km. were destroyed.
02-07-1930	Dhuburi (Assam)	7.1	Extensive damage to structures in Dhuburi, Cooch Bihar, Lakhimpur and Rangpur. Shocks were felt upto Calcutta, Chittagong (Bangladesh)· Dibrugarh, Manipur and Patna.
15-01-1934	Bihar-Nepal Border	8.4	Ruined large parts of Motihari, Darbhanga, Patna, and Kathmandu. About 10,000 people died. Shocks were felt over an area of 5 million sq. km. as far away as Lhasa in Tibet.
26-01-1950	Near Andamans	8.1	Large areas rocked. High waves in the sea.
15-08-1950	Assam-Epicentre at 29°N and 97°E	8.7	Shocks continued for 4-8 minutes and were felt over an area of 4.5 million sq. km. Widespread devastation in Assam and Arunachal Pradesh. Landslides blocked Subansiri river for a number of days. 1,530 people died.
21-07-1956	Anjar (Kuchchh Peninsula)	7.0	Heavy damage to buildings was caused in which about 100 people died.
27-06-1966	India/Nepal Border	6.1	Contiguous areas of India and Nepal were rocked.
11-12-1967	Koyna (Maharashtra)	6.3	Shock felt over a distance of 700 km. About 200 persons lost their lives and a few thousand were injured. Koyna Nagar razed.

13-04-1969	Bhadrachalam (Andhra Pradesh)	6.5	—
19-01-1975	Himachal Pradesh	7.5	Rocked parts of Kinnaur and Lahul Spiti
31-12-1984	Cachar	6.1	3000 dwellings destroyed in an area of 200 sq. km. around Sonai Town.
21-08-1988	Bihar	6.5	900 people killed in Bihar and Nepal.
20-10-1991	Uttarkashi	6.1	Large areas of Almora, Chamoli, Uttarkashi, Nainital, Dehradun and Moradabad in Uttar Pradesh and contiguous areas of Himachal Pradesh, China and Nepal were badly rocked. Tremors were felt upto Delhi.
30-09-1993	Lattur (Maharashtra)	6.0	Large areas in Maharasthra rocked. Lakhs rendered homeless. Ten thousand people lost their lives.
29-03-1999	Nandprayag (Chamoli Distt., U.P.)	6.8	Tremors felt over vast area including large parts of Uttar Pradesh, Himachal Pradesh, Punjab, Haryana and Delhi. Parts of China and Nepal were also affected. Widespread devastation was witnessed in Chamoli, Rudraprayag and other areas of Garhwal region. Chamoli turned into ghost town.

According to seismological studies, about two-thirds of India is earthquake-prone. The whole country is divided into three seismological zones depending upon the frequency and the intensity of the earthquakes.

1. Himalayan Zone

The areas most prone to earthquakes in India are the fold mountain ranges of the Himalayan zone. The states of Jammu and Kashmir, Himachal Pradesh, mountainous areas of Uttar Pradesh, Bihar, the Bihar-Nepal border and the north eastern states, especially Assam fall in this zone. The earthquakes in this zone are primarily due to plate tectonics. It is estimated that the Indian plate is pushing in the north and north-east direction at an annual rate of 5 cm. subducting the Eurasian plate along the Himalayas. The Himalayas have not yet attained *isostatic equilibrium* and are rising. The region along the Himalayas where two plates meet is highly earthquake-prone. This is known as the zone of maximum intensity. The absence of Nepal from the list of earthquakes shows that the whole of Himalayas are not dangerous. The Himalayas between Mount Everest and Badrinath are almost peaceful. This patch of tremendously huge land mass, having great heights and width rested with perfect calm and peace. The patches towards and beyond this patch are, however, very violent because of their hurried movement. Areas north-east of the arc joining Mussoorie, Shimla, Kangra, Dalhousie, Gulmarg and areas of Bihar Assam, south of south-east Nepal, Sikkim, Bhutan, Arunachal Pradesh and West of Nagaland, Manipur are susceptible to high magnitude earthquakes.

2. The Indo-Gangetic Zone

To the south of the Himalayan zone and running parallel it is the Indo-Gangetic zone. Most of the earthquakes striking this zone are of moderate intensity of 6 to 6.5 on Richter scale. Therefore, this zone is called the zone of *comparative intensity*. The earthquakes along the foothill are of medium to high intensity. However, the earthquakes of this zone are more harmful due to high density of population in this area.

3. The Peninsular Zone

The Peninsular India has presumably remained a stable landmass and only a few earthquakes have been experienced in this region. This region is, therefore, called the zone of minimum intensity. But severe earthquakes of Koyna (1967), Lattur (1993) and Jabalpur (1997), have raised doubts about the seismic stability of this landmass.

While the Koyna earthquake was caused due to excessive loading of water in the Shivaji Sagar reservoir formed by damming the Koyna River, the earthquake that hit Latur is supposed to be the result of plate tectonics. The northward drift of the Indian Plate had put pressure on the Tibetan Plate which caused pressure to mount at the centre of the Indian plate, leading to earthquake. The earthquake of Jabalpur also occurred under similar conditions.

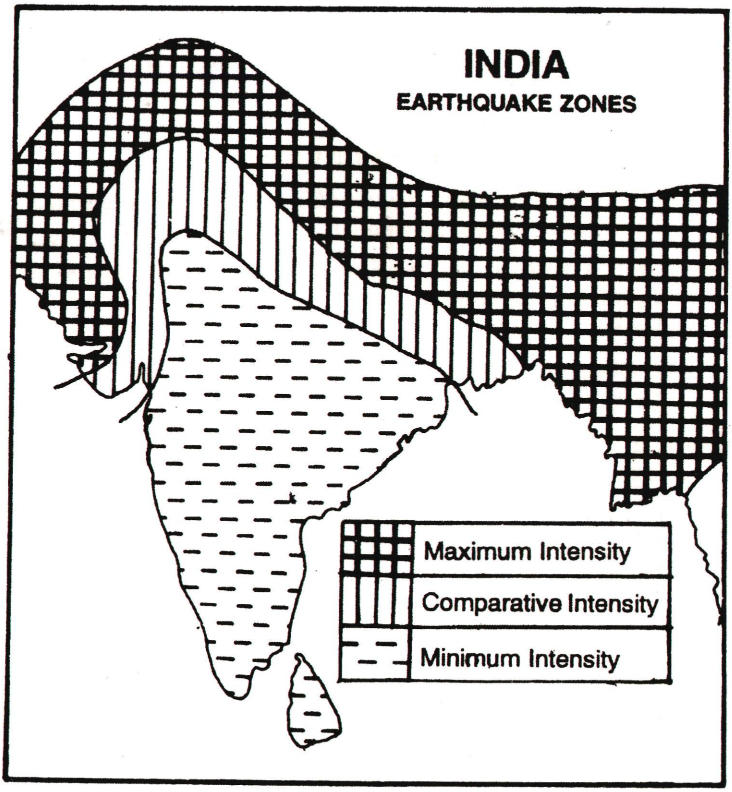
INDIA
EARTHQUAKE ZONES
Maximum Intensity
Comparative Intensity
Minimum Intensity

Fig. 5.13 : Seismic Belts of India.

VULCANICITY IN INDIA

At present there are not may volcanoes active in India but geological studies reveal that volcanic activity took place in India in the Dharwar, Cuddapah, Vindhayan, Peleozoic, Carboniferous and Mesozoic ages and also in the beginning of Tertiary age. Maximum volcanic erruption took place from the end of the Cretaceous till the beginning of the Eocene when large area of the Peninsular India was covered by lava. This area in the north-western part of the Peninsula is called the *Deccan Trap.*

Barren Island in the Bay of Bengal to the east of Andaman Islands, 12° 15' N lat., and 93° 54' E long., is a dormant volcano.

It erupted in quick succession in 1789, 1795 and 1803. It again erupted in 1992-93 after remaining dormant for about two centuries.

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6

NATURAL VEGETATION AND FOREST RESOURCES

INTRODUCTION

Natural vegetation is the primeval plant cover unaffected by man either directly or indirectly. The word forest is derived from Latin 'fores' meaning outside, the reference being to a village boundary or fence and it must have included all uncultivated and unhabited land. In general, a forest is defined as an area set aside for the production of timber and other forest produce or maintained under woody vegetation for certain benefits which it provides. Ecologically, a forest is a plant community predominantly of trees and other woody vegetation, usually with a closed canopy.

FACTORS AFFECTING VEGETATION

The geographical factors which influence natural vegetation include climate, soil and topography. The main climatic factors are rainfall and temperature. Generally speaking, rainfall is more important than temperature except in the Himalayas. The seasonal rainfall regime, the length of dry season and its relation to the march of temperature, are also important. The amount of annual rainfall has a great bearing on the type of vegetation. Areas receiving 200 cm or more rainfall per annum have stands of evergreen rain forests while monsoon deciduous forests dominate in areas with rainfall between 100 and 200 cm. In areas having 50 to 100 cm rainfall there are drier deciduous or tropical savana grading into open thorny scrub while those-with less than 50 cm rainfall have only dry thorny scrub and low open bush merging into semi desert. In higher attitudes of the Himalayas and the hills of the Peninsula at elevation of more than 900 metre above sea level, temperature plays more important role. As the temperature falls with altitude in the Himalayan region the vegetal cover changes from tropical to sub-tropical, temperate and finally alpine. Changes in soil conditions have given birth to different types of vegetation in different parts of the country. Mangrove forests, swamp forests, and beach and sandy coastal forests are some of the outstanding examples of influence of soil on natural vegetation,. Topography in the narrow sense is responsible for certain minor types *e.g.*,, alpine flora, lidal forests etc.

CLASSIFICATION OF NATURAL VEGETATION

A great variety of vegetation is found in different parts of India due to unequal distribution of rainfall and temperature as well as their seasonal variation, besides varied adaphic and biotic conditions. A generalised classification of Indian forests is, therefore, a difficult job. Various systematic classifications have been made by a number of botanists and ecologists. H.G. Champion (1936) distinguished 116 types of vegetation in India, some of them sub divided. Champion's classification has been much simplified by G.S. Puri (1960), Legris (1963), Champion and S.K. Seth (1968) and S.S. Negi (1990). Based on the suggestions of these scholars India's vegetation can be divided into 5 main types and 16 sub-types as per details given below :

A. Moist Tropical Forests

1. Tropical Wet Evergreen
2. Tropical Semi-Evergreen
3. Tropical Moist Deciduous
4. Littoral and Swamp

B. Dry Tropical Forest

5. Tropical Dry Evergreen
6. Tropical Dry Deciduous

7. Tropical Thorn.

C. Montane Sub-tropical forests

8. Sub-tropical broad leaved hill
9. Sub-tropical moist hill (pine)
10. Sub-tropical dry evergreen

D. Montane Temperate Forests

11. Montane Wet Temperate
12. Himalayan Moist Temperate
13. Himalayan Dry Temperate.

E. Alpine Forests

14. Sub-Alpine
15. Moist Alpine scrub.
16. Dry Alpine scrub.

A. MOIST TROPICAL FORESTS

1. Tropical Wet Evergreen Forests

These are typical rain forests which grow in those areas where the annual rainfall exceeds 250 cm., the annual temperature is about 25°-27°C, the average annual humidity exceeds 77 per cent and the dry season is distinctly short. Due to high heat and high humidity, the trees of these forests do not shed their leaves annually, at least not together, and are termed as evergreen forests. These are lofty, very dense multilayered forests with mesosphytic evergreens. The trees often reach 45 metres in height, individual, exceeding 60 metres. The entire morphology looks like a green carpet when viewed from above. The sun light cannot reach the ground and owing to deep shade, the undergrowth is formed mainly of tangled mass of canes, bamboos, ferns, climbers, etc. A variety of orchids flourish on the trees.

The true evergreen forests are found in along the western side of the Western Ghats (between 500 to 1370 metres above sea level) south of Mumbai, in a strip running from north-east to south-west direction across Arunachal Pradesh, Upper Assam, Nagaland, Manipur, Mizoram and Tripura upto a height of 1070 metres and in the Andaman and Nicobar Islands.

The timber of these forests is fine-grained, hard and durable as a result of which it has high commercial value. The important species of these forests are mesua, white cedar, calophyllum, toon, dhup, palaquium, hopea, jamun, canes, etc. in the Western Ghats and gurjan, chaplasha, jamun, mesua, agar, muli, bamboo etc. in the Himalayan region. Although, these forests contain valuable commercial species, they have not been properly exploited due to dense undergrowth, absence of pure stands and lack of transport facilities.

2. Tropical Semi-Evergreen Forests

Bordering the areas of tropical wet evergreen forests, are comparatively drier areas of the tropical semi-evergreen forests. Here the annual rainfall is 200-250 cm., the mean annual temperature varies from 24°C to 27°C and the relative humidity is about 75 per cent. Obviously these forests are found on the Western coast, Assam, lower slopes of the Eastern Himalayas, Orissa and Andamans.

The semi-evergreen forests are less dense but more gregarious (especially in Assam) than the wet evergreen forests. At places, these forests represent a transition from wet evergreen to deciduous forests. Further, these forests are characterised by many species, frequently buttressed trunks, rougher and thicker bark, heavy climbers, less bamboos and abundant epiphytes. The important species of these forests are aini, semul, gutel, mundani, *hopea*, benteak, kadam, irul, laurel, rosewood, mesua, haldu, kanju, byasal, kusum, thorny bamboo, etc. on the Western Ghats and bonsum, white cedar, Indian chestnut, *litsa*, bollock, champa, mango, etc. in the Himalayan region.

3. Tropical Moist Deciduous Forests

These forests are found in areas of moderate rainfall of 100 to 200 cm per annum, mean annual temperature of about 27°C and the average annual relative humidity of 60 to 75 per cent.

Such areas include a belt running along the Western Ghats surrounding the belt of evergreen forests both on the western and the eastern slopes, a strip along the Shiwalik range including terai and bhahar from 77°E to 88°E, Manipur and Mizoram, hills of eastern Madhya Pradesh, Chota Nagpur Plateau, most of Orissa, parts of West Bengal and in the Andaman and Nicobar islands.

The trees of these forests drop their leaves for about 6-8 weeks during the spring and early summer when sufficient moisture for the leaves is not available. The sub-soil water is not enough to enable the trees to retain their leaves throughout the year. The general appearance is burnt up and bare in April-May. These forests again become green when the leaves grow with the onset of the rainy season. Tropical moist deciduous forests present irregular top storey of different species, 25 to 60 metres high, heavily buttressed trees and fairly complete shrubby undergrowth with patches of bamboos, climbers and canes.

These are very useful forests because they yield valuable timber and several other forest products. The main species found in these forests are teak, sal, padauk, laurel, white chuglam, badam, dhup, chikrosi, kokko, haldu, rosewood, mahua, bijasal, lendi, semul, irul, dhaman, amia, kusum, lendu, paula, jamun, bamboo, etc. It is comparatively easy to exploit these forests due to their high degree of gregariousness.

These forests occupy much larger area than the evergreen forests but large tracks under these forests have been cleared for cultivation.

4. Littoral and Swamp Forests

These forests occur in and around the deltas, estuaries and creeks prone to tidal influences and as such are also known as *delta* or *tidal* forests. While littoral forests occur at several places along the coast, swamp forests are confined to the deltas of the Ganga, the Mahanadi, the Godavari, the Krishna and the Cauvery. The most peculiar feature of these forests is that they can survive and grow both in fresh as well as brackish water. Dense mangroves occur all along the coastline in sheltered estuaries, tidal creeks, backwaters, salt marshes and mudflats covering a total area of 6,740 sq. km. which is about seven per cent of the world's total mangrove area. It provides useful fuel wood. The most pronounced and the densest is the *Sunderban* in the Ganga delta where the predominant specie *Sundri* (Heriteera) grows abundantly. It provides hard and durable timber which is used for construction and building purposes as well as for making boats.

The important species found in these forests are Sundri, burguiera, sonneratia, agar, bhendi, keora, nipa, amur, bhara, rhizophora, screw pines, canes and palms, etc.

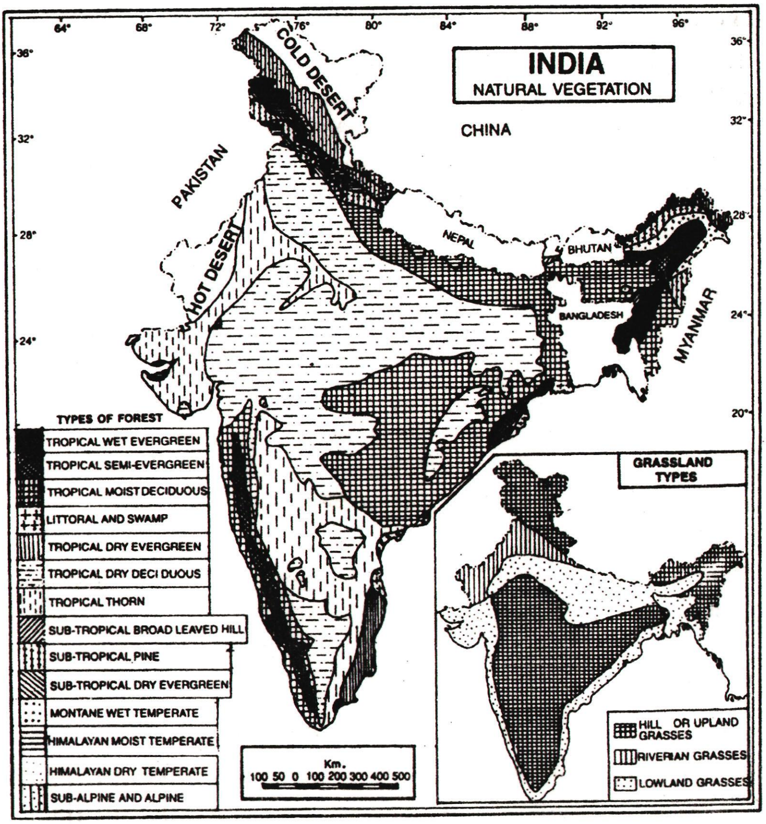
B. DRY TROPICAL FORESTS

5. Tropical Dry Evergreen Forests

Along the coasts of Tamil Nadu are areas which receive annual rainfall of about 100 cm. mostly from the north-east monsoon winds in October-December. Here, the mean annual temperature is about 28°C and the mean humidity is about 75 per cent. These areas are covered by the tropical dry evergreen forests. The growth of evergreen forests in areas of such low rainfall arouses great botanical interest, and the reason for such a phenomena is difficult to explain. It may be due to the seasonal distribution of rainfall. Most of rainfall occurs in winter. The chief characteristics of these forests are short statured trees, upto 12 m. high, with complete canopy, mostly of coriaceous leaved trees of short boles, no canopy layer differentiation, bamboos are rare or absent and grasses not conspicuous. The important species are *khirni, jamun, kokko, ritha, tamarind, neem, machkund, toddypalm, gamari* canes, etc. Most of the land under these forests has been cleared for agriculture or casuarina plantations.

6. Tropical Dry Deciduous Forests

These are similar to moist deciduous forests and shed their leaves in dry season. The major difference is that the species of dry deciduous forests can grow in areas of comparatively less rainfall of 100-150 cm. per annum. They represent a transitional type; on the wetter side, they give way to moist deciduous and on the drier side they degenerate into thorn forests. Such forests are characterised by closed and rather uneven canopy, composed of a mixture of a few species of deciduous trees, rising upto a height of 20 metres or so. Enough light reaches the ground to permit the growth of-grass and climbers. Bamboos also grow but they are not luxunant.


64°
68°
72°
76°
80°
84°
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92°
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36°
32°
28°
24°
20°
INDIA
NATURAL VEGETATION
CHINA
COLD DESERT
PAKISTAN
HOT DESERT
NEPAL
BHUTAN
BANGLADESH
MYANMAR
TYPES OF FOREST
TROPICAL WET EVERGREEN
TROPICAL SEMI-EVERGREEN
TROPICAL MOIST DECIDUOUS
LITTORAL AND SWAMP
TROPICAL DRY EVERGREEN
TROPICAL DRY DECIDUOUS
TROPICAL THORN
SUB-TROPICAL BROAD LEAVED HILL
SUB-TROPICAL PINE
SUB-TROPICAL DRY EVERGREEN
MONTANE WET TEMPERATE
HIMALAYAN MOIST TEMPERATE
HIMALAYAN DRY TEMPERATE
SUB-ALPINE AND ALPINE
Km.
100 50 0 100 200 300 400 500
GRASSLAND TYPES
HILL OR UPLAND GRASSES
RIVERIAN GRASSES
LOWLAND GRASSES

Fig. 6.1 : India—Forest Types.

The tropical dry deciduous forests are widely distributed over a large area. They occur in an irregular wide strip running north-south from the foot of the Himalayas to Kanniyakumari except in Rajasthan, Western Ghats and West Bengal. The important species are teak, axlewood, tendu, bijasal, rosewood, amaltas, palas, haldu, kasi, bel, lendi, common bamboo, red sanders, anjair, harra, laurel, satinwood, papra, achar, sal, khair, ghont, etc.

Large tracts of this forest have been cleared for agricultural purposes and these forests have suffered from severe biotic factors such as over cutting, over grazing and fire etc.

7. Tropical Thorn Forests

In areas of low rainfall (less than 75 cm), low humidity (less than 50 per cent) and high temperature (25°-30°C), there is not much scope for thick forests and only tropical thorn forests are found. The trees are low (6 to 10 metres maximum) and widely scattered. Acacias are very prominent, widely and pretty evenly spaced. Euphorbias are also conspicuous. The Indian wild date is common, especially in damper depressions. Some grasses also grow in rainy season.

These forests are found in the north-western parts of the country including Rajasthan, south-western Panjab, western Haryana, Kuchchh and neighbouring parts of Saurashtra. Here they degenerate into desert type in the Thar desert. Such forests also grow on the beside of the Western Ghats covering large areas of Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu.

The important species are khair, reunjha, neem, babul, thor, cactii, khejra, kanju, palas, ak, nirmali, dhaman, etc.

C. MONTANE SUB-TROPICAL FORESTS

8. Sub-tropical Broad-leaved Hill Forests

These forests are found in the eastern Himalayas to the east of 88°E longitude at altitudes varying from 1000 to 2000 m. where the mean annual rainfall is 75 cm. to 125 cm., average annual temperature is 18°-21°C and the average humidity is 80 per cent. They form luxurious forests of evergreen species, are fairly high (20-30 metres) and dense. Evergreen oaks and chestnuts predominate with some ash and beech. Sals and pines may occur on lower and higher margins respectively. Climbers and epiphytes are common. These forests are not so distinct in the southern parts of the country due to restricted area of southern hills. They occur in the Nilgiri and Paini hills at 1070-1525 metres above sea level. It is essentially a "stunted rain-forest" and is not so luxuriant as the true tropical evergreen. The higher parts of the Western Ghats such as Mahabaleshwar, the summits of the Satpura and the Maikal hills, highlands of Bastar and Mt. Abu in the Aravali hills also carry sub-types of these forests. But most of these forests have been destroyed, reduced and changed beyond recognition.

9. Sub-tropical Moist Pine Forests

These forests also occur at the same height as the wet hill forests *i.e.* at 1000 to 2000 metres above sea level but in the western Himalayas between 73°E and 88°E longitudes. Some parts of Arunachal Pradesh, Manipur, Naga Hills and Khasi hills of Meghalaya are also covered by such forests at similar altitudes. Chir or Chil is the most dominant tree which forms pure stands. It provides valuable timber for furniture, boxes, building and railway sleepers. It is also used for producing resin and turpentine. There is often a grassy floor with bulbous plants and little undergrowth, except for stunted evergreen oaks in wetter areas

10. Sub-tropical Dry Evergreen Forests

Like the tropical moist evergreen, this occurs in a restructed area and is found in the Bhabar, the Shiwaliks and the western Himalayas upto about 1000 metres above sea level. Here the rainfall is 50-100 cm. (15 to 25 cm in December-March). The summers are sufficiently hot and winters are cold enough for the occurrence of frequent frost. This is a low, practically scrub forest with small evergreen stunted trees and shrubs, including thorny species, herbs and grasses. Olive, acacia *modesta* and *pistacia* are the most predominant species. Considerable tracts are covered by dwarf creeping palm *Nonnorpops*.

D. MONTANE TEMPERATE FORESTS

11. Montane Wet Temperate Forests

This variety of forests grow at a height of 1800 to 3000 m. above sea level in areas where the mean annual rainfall is 150 cm. to 300 cm., the mean annual temperature is about 11°C to 14°C and the average relative humidity is over 80 per cent. This is mainly found in the higher hills of Tamil Nadu and Kerala, in the Eastern Himalayan region to the east of 88°E longitude including the hills of West Bengal, Assam, Arunachal Pradesh, Sikkim and Nagaland. These are closed evergreen forests in which the trees are mostly short-boled and branchy attaining a large girth. Leaves are dense and rounded. Branches are clothed with mosses, ferns and other epiphytes. Woody climbers are common. The trees rarely achieve a height more than 6 metres. Deodar, Chilauni, Indian chestnut, birch, plum, *machilus, cinnamomum, litsea, mangolia,* blue pine, oak, hemlock, etc. are important species.

12. Himalayan Moist Temperate Forests

Occuring in the temperate zone of the Himalayas between 1500 and 3300 metres where the annual rainfall varies from 150 cm. to 250 cm., the Himalayan moist temperate forests cover the entire length of this mountain range in Kashmir, Himachal Pradesh, Uttar Pradesh, Darjeeling and Sikkim. Such forests are mainly composed of coniferous species, mostly pure, 30 to 50 m. high. In the wetter east, the broad leaved evergreens are mixed with the dominant conifers. Pines, cedars, silver firs, spruce, etc. are most important trees. They form high but fairly open forest with shrubby undergrowth including oaks, rhododendrons, laurels and some bamboos. In comparatively drier western parts where the rainfall varies from 115 to 180 cm. especially to the west of 80°E longitude, deodar dominates the scene and forms pure stands. It provides fine wood which is of much use for construction, timber and railway sleepers.

13. Himalayan Dry Temperate Forests

These are predominantly coniferous forests with xerophytic shrubs in which deodar, chilgoza, oak, ash, mople, olive, celtis, parrotia, etc. are the main trees. Such forests are found in the inner dry ranges of the Himalayas where south-west monsoon is very feeble and the precipitation is below 100 cm., mostly snow. Such areas are in Ladakh, Lahul, Chamba, Kinnaur, Garhwal and Sikkim.

E. ALPINE FORESTS

The Alpine forests occur all along the Himalayas at altitudes ranging between 2,900 to 3,500 m. or even upto 3800 m. above sea level,. depending upon the location and the variety of species. These forests can be divided into :

(1) sub-alpine;

(2) moist alpine scrub and

(3) dry alpine scrub.

Table 6.1

S.No.	*Forest Group*	*Area in million hectares*	*Percentage of total area*
1.	Tropical Wet Evergreen	5.120	8.0
2.	Tropical Semi-evergreen	2.624	4.1
3.	Tropical Moist Deciduous	23.680	37.0
4.	Littoral and Swamp	0.384	0.6
5.	Tropical Dry Evergreen	0.128	0.2
6.	Tropical Dry Deciduous	18.304	28.6
7.	Tropical Thorn	1.664	2.6
8.	Sub-tropical Broad-leaved	0.256	0.4
9.	Sub-tropical Moist hill (pine)	4.224	6.6
10.	Sub-tropical Dry Evergreen	1.600	2.5
11.	Montane Wet Temperate	2.304	3-6
12.	Himalayan Moist Temperate	2.176	3.4
43.	Himalayan Dry Temperate	0.192	0.3
14.	Alpine (including sub-alpine, moist and dry alpine scrub)	1.344	2.1
	Total	**64-000**	**100-0**

Source : K. P. Sagreiya, Forests and Forestry (1994) p. 67,

The sub-alpine forests occur at the upper limit of tree forest adjoining alpine scrub and grasslands and comprise of dense growth of small crooked trees and large shrubs with coniferous overwood. It is a mixture of coniferous and broad-leaved trees in which the coniferous trees attain a height of about 30 m. while the broad leaved trees reach only 10 m. Fir, kail, spruce, rhododendron, plum, yew, etc. are important species.

The moist alpine scrub is a low ever- green dense growth of rhododendron birch, berberis and honeysuckle which occurs from 3,000 metres and extends upto snowline. The dry alpine scrub is the uppermost limit of scrub xerophytic, dwarf shrubs, over 3,500 metres above sea level and found in dry zone. Juniper, honeysuckle, artemesia, potentilla, etc. are important species.

As different forest groups grow under different geographical conditions, the area covered by each group differs greatly.

Apart from the major classification of Indian forests described earlier, the Indian forests may also be classified on the basis of statues, ownership, composition and exploitability.

1. Legal or Administrative Classification

This classification has been done to protect the forests against indiscriminate destruction. From legal or administration point of view, the Indian forests have been divided into :

(i) Reserved,

(ii) Protected, and

(iii) Unclassed.

Reserved and protected forests are permanent forests which are maintained for regular supply of timber and other forest products as well as for ecological reasons. They cover about 54 per cent and 29 per cent of the total forest area respectively. The unclassed forests amounting to about 17 per cent of the total forest areas is largely degraded, unproductive and unprofitable forest.

2. Classification Based on Ownership

Most of the forests are owned by the government through different departments such as forest department. Some of the forest land is owned by corporate bodies. A negligible proportion of less than 1 per cent is privately owned. Some forest land in

Meghalaya, Orissa, Panjab, and Himachal Pradesh is privately owned.

3. Classification According to Composition

Mainly two types of forests are recognised according to composition. They are :

(i) Coniferous, and

(ii) Broad leaved.

The *Coniferous forests* cover only 3.5 million hectares and are mainly confined to the Himalayan ranges. Some species of the coniferous forests are deodar, chir, fir, spruce, pine, etc. Though, they contain valuable softwood timber, they are not properly exploited due to their inaccessibility, difficult terrain and lack of transport facilities.

The broad leaved forests are widely spread and cover about 95 per cent of the total forest area of the country. Sal and teak are the most important species and provide valuable timber. They cover about 16.55 per cent and 13.82 per cent of the total area under broad leaved forests respectively. Bamboo covers about 7.48 per cent of the total area under broad leaved forests. The other species of the broad leaved forests are rosewood, Indian laurel, shistram, garyan and benteak.

4. Classification According to Exploitabilty

From the exploitability point of view, the forests can be classified into :

(i) exploitable,

(ii) potentially exploitable, and

(iii) others.

About half of our forests are exploitable. Most of them supply non-coniferous timber. About one fourth of the forests are potentially exploitable. Both the exploitable and potentially exploitable forests occur in Assam, Arunachal Pradesh, Tripura, Western Ghats, Satpura, Maikal, Chota Nagpur plateau, Andaman and Nicobar Islands, Orissa and adjoining areas of Andhra Pradesh and Madhya Pradesh.

Large proportion of our forests is inaccessible for effective exploitation and are also termed as *non-merchantable*. They lie in the high reaches of the Himalayas in Kashmir and Arunachal Pradesh where they cannot be exploited due to lack of transport facilities.

GEOGRAPHICAL DISTRIBUTION OF FOREST AREA

The total geographical area of the country is 32,87,263 sq. km. out of which an area of 7,70,078 sq. km. or 23.43 per cent is under forests. This is much below the average of 30.4 per cent for the world.

The picture is very gloomy when we compare our percentage of forests area with 34.4 per cent of Canada, 36.0 per cent of Germany, 41.07 per cent of the U.S.A., 57.8 per cent of Sweden and 67.6 per cent of Japan.

India with 16 per cent of the world's population has nearly 2 percent of the total forests, and if the forest growing stock has been correctly estimated, it is one of the lowest per unit area *i.e.*, less than 1 per cent of that of the forests of the world.

According to the National Forest Policy, the minimum desired area which is considered safe for a tropical country like India is about 33 per cent.

As per broad policy recommendations, about 60 per cent of the area in the Himalayas and the Peninsular hills and 20 per cent in the Great Plains should be under forests. Furthermore, the per capita forest area in India is bare 0.09 hectare against the world average of 1.08 hectare.

The per capita forest cover is 1.8 hectare in the U.S.A., 3.2 hectare in Sweden, 3.5 hectare in Russia, 5.1 hectare in Australia, 8.6 hectare in Brazil and 22.7 hectare in Canada.

The production of Indian forests is also very low, being only 0.5 cubic metre per hectare a year as against the world average of 2.1 cubic metres per hectare per year. Thus, the useful forest resources are extremely inadequate for a predominantly agricultural country like India.

Table 6.2. Distribution of Forests in India

S. No.	State/UTs	Recorded forest area (sq. km.)	% of forest area of geographical area	Per Capita forest area in hectares
1.	Andhra Pradesh	63,726	23.2	0.10
2.	Arunachal Pradesh	51,540	61.5	6.00
3.	Assam	30,708	39.1	0.14
4.	Bihar	29,226	16.3	0.03
5.	Goa (Including Daman & Diu)	1,256	32.9	0.10
6.	Gujarat	19,388	9.9	0.05
7.	Haryana	1,687	3.9	0.01
8.	Himachal Pradesh	37,591	67.7	0.74
9.	Jammu & Kashmir	20,174	9.1	0.26
10.	Karnataka	38,646	20.2	0.09
11.	Kerala	11,222	28.9	0.04
12.	Madhya Pradesh	1,55,414	35.0	0.23
13.	Maharashtra	63,861	20.3	0.08
14.	Manipur	15,154	67.9	0.03
15.	Meghalaya	9,496	42.3	0.54
16.	Mizoram	15,935	75.6	2.32
17.	Nagaland	8,625	52.0	0.71
18.	Orissa	59,555	38.2	0.19
19.	Punjab	2,842	5.5	0.01
20.	Rajasthan	31,539	9.2	0.07
21.	Sikkim	2,650	37.3	0.66
22.	Tamil Nadu	22,599	17.5	0.04
23.	Tripura	6,292	60.0	0.23
24.	Uttar Pradesh	51,502	17.5	0.04
25.	West Bengal	11,379	13.4	0.02
26.	Andaman & Nicobar Isands	7,171	86.9	2.58
27.	Chandigarh	31	27.2	0.005
28.	Dadra & Nagar Haveli	207	42.2	0.15
29.	Delhi	42	2.8	
30.	Lakshadweep		—	
31.	Pondicherry		—	
	Total	**7,70,078**	**23-4**	**0-09**

Note : Recorded forest area pertains to period 1989.

The forest resources are very unevenly distributed in India. Madhya Pradesh has the largest area of 155.4 thousand sq. km. under forests. The other states with considerable area under forests are Maharashtra (63.9 thousand sq. km.), Andhra Pradesh (63.7 sq. km.), Orissa (59.6 sq. km.), Arunachal Pradesh (51.5 sq. km.) and Uttar Pradesh (51.5 sq. km.). Incidently, most of them are very large states and the total forest area is not a good index of forest prosperity.

Percentage of forest area to total area can serve as a better index of the forest cover. Unfortunately, the forests are conspicuous by their absence where they are needed the most. For example only 5 per cent of the total area in the thickly populated Ganga plain is under forests. In the north-west India about 11 per cent of the area is under forests while the forests cover about 20 per cent of the area in Tarai. As per percentage of forest area to total area, Andaman and Nicobar Islands (86.9%), Mizoram (75,6%) Manipur (67.9%) Himachal Pradesh (67.7%), Arunachal Pradesh (61.5%) Tripura (60%) and Nagaland (52%) are in a very comfortable position where more than half of the area is under forests. Forest cover is also reasonably good in Meghalaya, Orissa, Assam, Sikkim, Madhya Pradesh and Dadra and Nagar Haveli where more than one third of the land area is under forests. But there are other states where the percentage of forest area to total area is desperately low. For example Panjab and Haryana have only 5.5 and 3.9 per cent of their land under forests respectively. The other states where the percentage of forest area is below the national average are Bihar, Gujarat, Jammu and Kashmir, Karnataka, Kerala, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal. Delhi has only 2.8 per cent of its total area under forests.

Still a better Index is the per capita forest area which is defined as the forest area per person. Arunachal Pradesh with a per capita forest area of 6.00 hectares is the richest state in India. But the state also has the lowest population density among all the Indian states. The other states and union territories with sufficiently higher per capita forest area are Andaman and Nicobar Islands (2.58 hectare), Mizoram (2.32 hectare), Himachai Pradesh (0.74 hectare), Nagaland (0.71

hectare), Sikkim (0.66 hectare) and Meghalaya (0.54 hectare). On the other end of the scale there are other states where the per capita forest area is desperately low. These include Punjab and Haryana (0.01 hectare each), West Bengal (0.02 hectare), Bihar (0.03 hectare) and Kerala and Tamil Nadu (0.04 hectare each). As many as eleven states and union territories have per capita forest area below the national average which in itself is very low when compared with the world average.

There are different reasons for lack of forest cover in different parts of the country. In Rajasthan and the adjoining parts of Haryana, Punjab and Gujarat it is the scarcity of rainfall which is responsible for low forest cover. In larger parts of Punjab and Haryana most of the forests have been cleared and brought under plough. Similarly, vast areas of natural vegetation have been replaced by cultivated area in other parts of the country. The only areas where forests can be found in Bihar are the Himalayan foothills and the Chota Nagpur plateau.

In Uttar Pradesh the Kumaon region in the north and the Chambal ravines in the south have forests. This is due to the fact that these areas in Bihar and Uttar Pradesh are not much suitable for, cultivation and have not been cleared for this purpose. In Jammu and Kashmir, the low percentage ~~of the~~ forest area is primarily due to low rainfall, steep barren slope and snow covered peaks. The semi-arid lands of Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu in the rain-shadow of the Western Ghats receive much less rainfall and are devoid of thick forest growth. The coastal areas of Tamil Nadu and Andhra Pradesh receive sufficient rainfall in winter and support good forest cover but most of the forests in this region have been cleared for cultivation.

The forest areas do not follow political boundaries, and as such it would be better to study their growth and distribution according to the geographical conditions governing them. The areas more conductive for the forest growth are those receiving heavy rainfall, having sufficiently high temperature and soils as well as relief suitable for the forest growth (see figure 8.2). Table 6.3 given below would help in understanding the geographical distribution of forests in India.

Table 6.3 : Geographical distribution of forests in India

S.N.	*Geographical Region*	*Percentage of total forest of India*
1.	Himalayan Region	18.00
2.	The Great Plain of India	5.00
3.	Peninsular plateaus and hills	57.00
4.	Western Ghats and Western Coastal Plain	10.00
5.	Eastern Ghats and Western Coastal plain	10.00
	Total	**100.00**

Grass Lands

The areas receiving less rainfall and devoid of deep soil cover cannot support the growth of trees, and only grasses grow under such geographical conditions. Although, grasses equivalent to prairies, steppes and savanas may not be available in India, yet some areas do have good grasses which are used both for grazing and as industrial raw materials. Generally speaking, grasses of India are divided into three categories, viz.:

(1) Hilly or upland grasses

(2) Low Land grasses, and

(3) Riverain grasses.

1. Hilly or Upland Grasses

As their name indicates, these grasses are mainly related to altitude and are usually found above 1000 metres in the Himalayan region. There are vast tracts of luscious, sweet grasses between the shifting snow line and the tree line. Between 2,450 and 3,400 metres there are large patches of grassy slopes in the midst of thick pine, oak or deodar trees. Above 3,400 metres, the temperature is too low for forest growth and its place is taken by grasslands which extend upto the line of perpetual snow. On the Western Ghats, they are found in those areas where forests have been cleared up. Extensive grass cover occurs on the slopes of Nilgiris and other South Indian Hills. Here the grass is often interspersed with small isolated *Shola* forests.

2. Low Land Grasses

The plains of Punjab, Haryana, Uttar Pradesh, Bihar, and Assam have low land grasses. These grasses grow on a variety of soils ranging from the red and yellow, red and brown, sandy, loam and mixture of alluvium and leterites. Both perennial and the annual grasses grow and provide excellent fodder to some of the best known breeds of cattle and buffaloes.

3. Riverain Grasses

There are some areas of riverain grasses in Northern India, the most important being known as Bhabar pastures. These grasses occur on alluvial sandy loam soil in areas where there are extremes of temperature. More than a dozen species of grass grow in these areas. These are very important grasses because they provide good fodder for cattle and buffaloes.

FORESTS PRODUCTS

Forests constitute one of the major natural resource of India. They produce a large variety of woods which are used as fuel, timber and industrial raw material. They also provide many more things out of which bamboos, canes, herbs, drugs, lae, grasses, leaves, oils, etc. are important. Accordingly the forest products of India are classified into two categories viz., major products and minor products.

Major Forest Products

Major forest products consist of timber, smallwood and fuelwood including charcoal. Indian forests produce about 5,000 species of wood, of which about 450 are commercially valuable. Both hard and soft woods are produced by Indian forests. *Hard woods* include important species such as teak, mahogany, logwood, iron-wood, ebony, sal, greenheart, kikar, semal, etc. These woods are used for furniture, wagons, tools, etc. *Soft* *woods* include deodar, poplar, pine, fir, cedar, balşam, etc. They are light, strong, fairly durable and easy to work and as such are very useful for cosntructional timbers. They also provide useful raw materials for making paper pulp. It is interesting to note that 70 per cent of hard wood is burnt as fuel and only 30 per cent is used in industries while 70 per cent of the soft wood is used in industries and only 30 per cent is burnt as fuel.

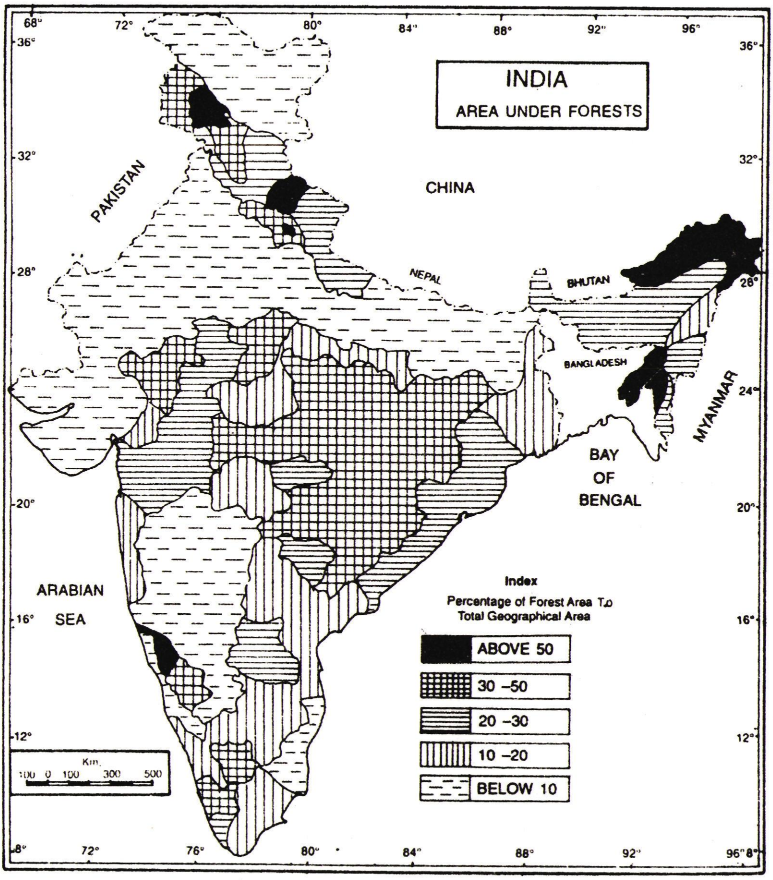
INDIA
AREA UNDER FORESTS
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
MYANMAR
BAY OF BENGAL
ARABIAN SEA
Index
Percentage of Forest Area To Total Geographical Area
ABOVE 50
30 -50
20 -30
10 -20
BELOW 10
Km.
100 0 100 300 500
68° 72° 76° 80° 84° 88° 92° 96°
36° 32° 28° 24° 20° 16° 12° 8°

Fig. 6.2 : Area under Forests.

Forests meet about 40 per cent of energy needs of the country including more than 80 per cent of the rural energy requirements. The current production of wood is about 52 million cubic metres out of which about 40 million cubic metres or nearly 77 per cent of total is used as fuel wood.

The current production of wood is too short of our present demands which is increasing at alarming rate. It has been estimated that our fuel wood requirements by 2010 will be 350 million cubic metres. The increase in demand for industrial wood will be much more keeping in view the large scale industrialisation in the country.

Minor Forest Products

Minor forest products include all products obtainable from the forests other than wood and thus comprise products of vegetable and animal origin. Some of the important forest products of minor nature are described as under:

1. Grasses, bamboos and canes.
2. Tans and Dyes
3. Oils
4. Gums and Resins
5. Fibres and Flosses
6. Leaves
7. Drugs, Spices and Poisons
8. Edible Products.
9. Animal Products.

1. Grasses, Bamboos and Canes

Different types of grasses grow in different parts of the country. Most of the grasses are used as fodder or for thatching, but some grasses are better used for cordage, matting and as an important raw material for manufacturing paper. Grasses like *sabai*, bhabar and elephant are used for paper making. Sabai is the most important grass which provides the basic raw material for paper industry. It is a perennial grass which grows on the bare slopes of the sub-Himalayan tract and in Bihar, Orissa, West Bengal, Madhya Pradesh and Western part of

Himachal Pradesh. Annually over two million tonnes sabai grass is collected and supplied to paper mills. The roots of *khus* grass are used for making cooling screens. *Munj*, a tall grass is used for making chicks, stools, chairs, etc. and the leaves are twisted into strings.

Bamboo belongs to grass family but grows like a tree. It is woody, perennial and tall. It may attain a size of as much as 30 metres. More than 100 species of bamboos grow in the Indian forests covering an area of over one lakh sq. km. Andhra Pradesh (19.7 thousand sq. km.), Madhya Pradesh (14.9 thousand sq. km.), Orissa (10.5 thousand sq. km.), Assam (10.0 thousand sq. km), Arunachal Pradesh (7.8 thousand sq. km.) and Karnataka (6.0 thousand sq. km) are the main areas of its growth.

Bamboo is called the poor man's timber as it provides cheap material for roofing, walling, flooring, matting, basketry, cordage, carthoods and a host of other things. Young tender culms are eaten; the seed is collected and eaten as grain. However, the most significant use of the bamboo is for making pulp for the production of paper and newsprint. Of the total bamboo consumed in India, 32 per cent is for construction, 30 per cent for rural use, 17 per cent for making paper pulp, 7 per cent for packaging and the remaining 14 per cent for other purposes.

Cane grows abundantly in moist forests of Andaman and Nicobar, Assam, West Bengal, Kerala, Karnataka, Tamil Nadu, Maharashtra, Bihar, Orissa and Uttar Pradesh. It is mainly used for making strings, ropes, mats, bags, baskets, furniture, walking sticks, umbrella handles, sports goods, etc.

2. Tans and Dyes

Tannins are secretion products of plant tissues. Tanning materials are used in leather industry. The most commonly used tanning materials are mangrove, amia, oak, hemlock, anwal, wattle, myrobalans, ratanjot, flowers of dhawri, babul, avaram, etc.

Some of the important dyes are obtained from red sander (bright red), khair (chocolate), flowers of Palas, fruits of *Mallotus* *phillipensis*, bark of wattle and roots of *Morinda tinctoria*. About two lakh tonnes of tans and dyes are produced every year in India.

3. Oils

A large number of plants and trees which grow in Indian forests contain several types of oils which are used to manufacture soaps, cosmetics, confectionary, pharmaceutical preparations and many more things. Commercially important oils are those obtained from sandalwood, lemon grass, khus and eucalyptus globulus.

4. Gums and Resins

Gums are exuded from the stems or other parts of different trees, partly as a natural phenomenon and partly by injury to the bark or wood or blazing the tree. The most important gum is Karaya obtained from *Sterculia urens* or *S. villosa* trees of dry deciduous forests. It is mainly used in textiles, cosmetics, confectionery, medicines, inks, pastes, cigar, etc. Madhya Pradesh, Uttar Pradesh, Rajasthan and Gujarat are the main producers. A large proportion of Indian gums is exported to the USA, the UK and France.

Resin is obtained mainly from Chir pine which grows in the Himalayan region in Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir and Punjab. Crude resin consists of two principal constituents; a liquid known as oil of turpentine (25%) and a solid called resin (75%). They are separated after distillation. Turpentine is mainly used as a solvent for paints and varnish, synthetic camphor, pine oil, disinfectants, pharmaceutical preparations, wax, boot polish and industrial perfumes. Resin is an important raw material for several industries of which paper, paint, varnish, soap, rubber, water proofing, linoleum, oils, greases, adhesive tape, phenyle, plastic, etc. About 44,000 thousand metric tonnes of crude resin is produced annually.

5. Fibres and Flosses

Fibres are obtained from the tissues of some trees. Most of such fibres are coarse and are used for rope making. However, the fibres of Ak (Calotropis spp.) is fine, strong and silky which is used for making fishing nets. Flosses are obtained from certain fruits and are used for stuffing pillows, mattresses, etc.

6. Leaves

Different types of leaves are obtained from the trees and are used for different purposes, the most important being the tendu leaves used as wrappers for bidis. The tendu tree grows in large numbers in Madhya Pradesh and Orissa and to a lesser extent in Andhra Pradesh, Bihar, West Bengal, Maharashtra, Tamil Nadu, Gujarat, Rajasthan and U.P. About 6 lakh tonnes of tendu leaves are produced every year in India, out of which 2 lakh tones come from Madhya Pradesh, 1.8 lakh tones from Maharashtra and 1.2 Lakh tones from Orissa, Tendu leaves and *bidis* are exported to Pakistan, Bangladesh, Sri Lanka and some other Asian and African countries.

Leaves of *Bauhinia vahlii* are converted into plates and leaf cups and are also used as wrappers by vendors of sweets.

7. Drugs, Spices and Poisons

Thousands of drugs are obtained from fruits, flowers, roots, stems and leaves of different types of trees, plants and herbs. Quinine is the most important drug obtained from the Indian forests.

Spices are used to add aroma or pungency to food to flavour certain dishes. The important spices are galangal, cinnamon or *Dalchini*, lesser cardaman (*Chhoti Ilaychi*), greater cardomon (*Baui Ilayachi*), etc.

Indian forests produce some poisonous substances which can act as good medicines when taken in small regular doses. Some outstanding poisons are strychnine, aconite, datura, ganja etc.

8. Edible Products

Fruits, flowers, leaves or roots of various species provide edible products. Mango, *bel, her, jamun, khirni, phalsa, sitaphal,* etc. are important fruits obtained from the forests. Among the kernels cashewnut, *akhrot* or Walnut, *achar, chilgow* and *kimal* are important. *Amla, anar, imli, karaunda, munga, kachnar,* *kaith, mushroom, zimikand, guchchi,* etc. are important products used as pickles or vegetables. Palmyrah, palm, mahua, corollas are used to obtain liquor and their seeds are eaten. *Tejpata,* used for flavouring curries are leaves of a small evergreen tree.

9. Animal Products

Lac is the most important animal product obtained from the forests. It is secreted by a minute insect (*Laccifer laced*) which feed on the saps of a large variety of trees like palash, peepul, kusum, sissoo, sisir, kul, gular, ber, banyan, jujuba and ghont. These trees grow extensively in the Chota Nagpur plateau of Bihar, eastern districts of Madhya Pradesh, Western border areas of West Bengal, eastern part of Maharashtra, northern districts of Orissa and to a lesser extent in Assam, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Karnataka and Punjab. India practically holds monopoly in the production of lac. The current annual production of lac in India is about 18.5 thousand tonnes which is about 85 per cent of the world production.

The main producing states are Bihar (40%), M.P. (30%), W. Bengal (15%), Maharashtra (5%), Gujarat, U.P., Orissa and Assam.. About 95% of the total production is exported. Our main customers are the USA, Russia, Germany and U.K. At present it is widely used in medicines, plastics, electrical insulation material, dyeing silk, making bangles, paints, sealing wax, gramophone records, leather and wood finishing, ornamental articles, etc.

The other animal products are honey, wax, silk moths, horns and hides of dead animals, ivory, antlers of deer, etc.

The above mentioned major and minor forest products are used for various purposes and form an important sector of Indian economy. About 3.5 million persons are engaged in different forest activities. About two per cent of the government revenue comes from the forests. There has been a steady increase in government revenue from the forests. In some states like Maharashtra, Uttar Pradesh, Karnataka, Kerala, Orissa and Andhra Pradesh, gross revenue from forests is far greater than the expenditure on forest activities. Some foreign exchange is also earned by exporting forest products.

INDIRECT USES OF FORESTS

Apart from their direct uses described above, the forests are of immense use to man indirectly also. They prevent soil erosion, regulate the flow of rivers and reduce the floods, check the spread of deserts, add to soil fertility and ameliorate the extremes of climate.

1. *Prevention and control of soil erosion :* Forests play a significant role in the prevention and control of soil erosion by water and wind. The destruction of forest cover leads to increased runoff of rain water and its diminished seepage and storage in soil. The structure of the soil suffers, the runoff increases and loosens the soil which is carried away to other regions. The fertility of the soil is thus lost, and it becomes barren and unproductive. The reckless destruction of forests in the Shiwalik hills. Western Ghats, Chota Nagpur plateau and in the Deccan table-land has resulted in serious problem of soil erosion. The most effective way to check soil erosion is to stop reckless cutting of forests and to plant more trees.
2. *Flood Control :* Roots of the trees absorb much of the rain water and use it slowly during the dry season. Thus they regulate the flow of water and help in controlling the floods. The forest cover acts as a *rain-holder* and a *rain banker*. The trees also act like millions of tiny dams and check the flow of water like a barrage. With the increased rate of deforestation, the frequency and the intensity of floods has increased in different parts of the country. In the absence of the forests, the increased runoff, especially after heavy downpour, comes in a sudden rush and often gets blocked in the silted streams and cause devastating floods.
3. *Checks on spread of deserts :* Sand particles are blown away by strong winds in the deserts and are carried over long distances, thus resulting in the spread of deserts. The roots of trees and plants bind the sand particles and do not permit their easy transportation by wind. Therefore, the forests are a great instrument to

put a check on the spread of deserts. In the long run, the forests add humidity to the atmosphere and further help in checking the spread of the deserts. A great success has been achieved in checking the march of the Thar desert by planting 650 km. long and 8 km. wide strip of trees on its periphery.

4. *Increase of soil fertility :* The fallen leaves of trees add humus to soil after their decomposition. Thus forests help in increasing the fertility of soil.
5. *Effect on Climate :* Forests have a far reaching effect on climate. They ameliorate the extremes of climate by reducing the heat in summer and cold in winter. They also influence the amount of rainfall by lowering the temperature of moisture laden winds and increase the relative humidity of the air through the process of transpiration. They reduce the surface velocity of winds and retard the process of evaporation.

FOREST PROBLEMS

The biggest problem of the Indian forests is the inadequate and fast dwindling forest cover. It has already been mentioned that forests cover only 23.43 per cent of the area against the required coverage of 33 per cent. Even this small percentage of forest cover is seriously threatened by the increasing demand for major and minor forest products. These products are badly needed for fuel, building and to feed a large number of forest based industries. Vast forest tracts have been cleared for agriculture. Shifting agriculture in different parts of the country has played havoc with forests. Overgrazing is a big factor which is responsible for serious damage to forests. India possesses a livestock population of over 412 million of which 270 million are bovine animals, about one-tenth of which graze in the forests. Whenever forests are easily accessible, the livestock entirely depends on grazing in them.

The forests are thick, inaccessible, slow growing and lack in gregarious stands in many parts of the country. Some of them are very thin and comprise only of thorny bushes. These factors make their utilization uneconomical because there is good deal of wastage and it makes very expensive in spite of the cheap labour available in India.

One of the biggest problems faced by the Indian forests is the lack of proper transport facilities. About 16 per cent of the forest land in India is inaccessible and does not have proper transport facilities. It must be remembered that the major product of the forests is timber which is a cheap and bulky commodity. As such it cannot afford high freight charged by the railways and roadways. Therefore, they cannot be economically exploited without the availability of cheap and efficient transport facilities. Unfortunately, in India, the railways serve thickly populated areas only and are not of much use to forests. All weather roads in the forest areas are badly lacking. Water transport has only limited scope. Considering these facts we can easily say that transport with reference to forests is inadequate in India.

Large tracts of vegetal cover are destroyed every year by forest fires. Forest fires in India are most destructive in dry season. Insufficiency of properly trained personnel is also a big handicap.

FOREST POLICY AND LAW

Forest policy was first declared by the British Government of India on 19 October, 1894 at the recommendation of Dr. Voelcker, a German expert who studied the role of forests vis-a-vis agriculture. With the passage of time and with India becoming an Independent country, major changes of economic and political nature took place. The population, both of human beings and livestock, had increased very substantially, resulting in a heavier pressure on the forests for securing more land for agriculture and pasturage. The reconstruction schemes also leaned heavily on the forest products. The Government of free India thought it desirable to come out with a new National Forest Policy in 1952. While retaining the major clauses of the earlier forest policy, this policy laid greater emphasis on some other points also. It proposed the classification of forests on a functional basis into *protection forests, national forests and village forests*. The policy recommended the establishment of tree-lands wherever possible. It also stressed upon increasing pastures and timber and made a strong plea against the indiscriminate extension of agriculture by excision of forests. The policy also stressed that the productive, protective and bio-aesthetic roles of forest entitle them to an adequate share of land. It also emphasised the need to protect wildlife. The policy laid stress on:

(i) Weaning the primitive people by persuation, from the baneful practice of shifting cultivation,

(ii) Increasing the efficiency of forest administration by having adequate forest laws,

(iii) Giving requisite training to the staff of all ranks,

(iv) Providing adequate facilities for management of forests and for conducting research in forestry and forest products utilization.

(v) Controlling grazing in the forestry and

(vi) Promoting welfare of the people.

The country made rapid strides after Independence under planned development and changes of far reaching consequences occurred in the economic, political, environmental and social set up of the country since the forest policy of 1952 was declared. Therefore, the Government of India came out with a new forest policy in December, 1988. The main plank of the revised forest policy of 1988 is protection, conservation and development of forests. Its aims are:

(i) Maintenance of environmental stability through preservation and restoration of ecological balance

(ii) Conservation of natural heritage;

(iii) Check on soil erosion and denudation in catchment area of rivers, lakes and reservoirs;

(iv) Check on extension of sand dunes in desert areas of Rajasthan and along coastal tracts;

(v) Substantial increase in forest/tree cover through massive afforestation and social forestry programmes;

(vi) Steps to meet requirements of fuel wood, fodder, minor forest produce and soil timber of rural and tribal populations;

(vii) Increase in productivity of forest to meet the national needs;

(viii) Encouragement of efficient utilisation of forest produce and optimum substitution of wood and

(ix) Steps to create massive people's movement with involvement of women to achieve the objectives and minimise pressure on existing forests.

SOCIAL FORESTRY

Social forestry means the management and protection of the forests as well as afforestation of barren lands aimed at helping in environmental, social, and rural development as against the traditional objective of securing revenue. It is aptly described as *forestry of the people by the people and for the people.* The main thrust of social forestry is to reduce pressure on the traditional forests areas by developing plantations of fuelwood, fodder and grasses. Social forestry has become very popular during the last three decades. Agro forestry, community forestry, commercial farm forestry, non-commercial farm forestry and urban forestry are the main components of social forestry. *Agro forestry* involves the raising of trees and agricultural crops either on the same land or in close association in such a way that all land including the waste patches is put to good use. This enables the farmer to get food, fodder, fuel, fruit and timber from his land. The land gives maximum production and provides employment to rural masses. Community forestry involves the raising of trees on public or community lands aimed at providing benefit to the community as a whole. Although the plants and seedlings are provided by the forest department, the protection of plantations is primarily the responsibility of the community as a whole. India is second only to China in community forestry. Remarkable success has been achieved in community forestry in some major states like Gujarat, Tamil Nadu, Rajasthan, Kerala, Karnataka, Uttar Pradesh, Haryana, Orissa and Himachal Pradesh. *Commercial farm forestry* involves growing of trees in the fields in place of food and other agricultural crops. In this way, the farmers grow trees for direct commercial gain. This type of forestry has become very popular in Haryana, Punjab, Gujarat, Uttar

Pradesh, Rajasthan and in some parts of south India. Farmers in these areas grow eucalyptus, poplars, and casuarina in their land and sell them to paper, pulp, rayon and match industries and also use them for making packing cases and fuel. The state governments are encouraging this forestry in a big way. Non-commercial farm forestry involves tree planting by farmers on their own land for their own use and not for sale. The land mainly used for this purpose includes margins of agricultural fields, wastelands and marginal lands which are not usually cultivated, grasslands and pastures and land around homes and cowsheds. This type of forestry is practised in Gujarat, Haryana, Kerala and Karnataka for obtaining fuel, fodder and fruit. *Urban forestry* pertains to raising and management of trees on public and privately owned lands in and around urban centres. It includes green-belts, roadside avenues, recreational parks, wildlife parks, etc. Its main objectives are reduction of environmental pollution, recreation and improving aesthetic values.

FOREST CONSERVATION

Forests comprise a unique gift of nature to man and constitute one of the prized assets of a nation. They play a significant role in the national economy of a primarily agricultural and developing country like India. The agricultural and industrial progress of the country is not only stabilized but accelerated by a proper conservation and utilization of forest resource. As mentioned earlier, the uses of forests, both direct and indirect, are so large that they are aptly termed as *an index of prosperity of a nation*. Keeping in view the benefits which we derive from the forests, it is of utmost importance that strong steps should be taken to conserve forests.

Our increased demands for forests products has led to increasing destruction and degration of our forests which is causing heavy erosion of top soil, erratic rainfall and frequent devastating floods. In short, depletion of forests has a chain reaction in eco-system. Though it is a renewable resource, it takes its own time to regenerate. We have been destroying our forest resources so ruthlessly and so quickly that large forest tracts of yesteryears are now devoid of any forest cover.

India's woods, once dark and deep, are now a living example of man's ravage destruction. The saying that *man finds forests but leaves deserts could not be more true to India*. Over the past four decades, about 25 million hectares of land that originally had tree cover has been laid bare for agriculture and other purposes. The latest reports of the National Remote Sensing Agency (NRSA) indicates that the country is losing about 1.3 million hectares of forest cover every year. This will be detrimental to our national interest. Nature never forgives the abuse of her gift. Hence, the urgent need for conservation of forests.

Forest conservation does not mean the denial of use, but rather the proper use without causing any adverse affect on our economy or environment. But any scheme of conservation of forests on a piecemeal basis will not solve the problem. Conservation of forests is a national problem and should be tackled as such. There should be perfect coordination between the forest department and other departments for an effective conservation of forests. People's participation in any forest conservation is of vital importance. *Van Mahotsava* was launched in 1950 to make people aware of the importance of planting trees. *Chipko movement* is a living example of general public awareness about forests.

Forests have to be developed and worked for obtaining various raw materials and for providing an effective means of flood control, soil erosion, for regulating the flow of water in streams and for conserving moisture in the soil. Therefore, a carefully coordinated scientific policy for conservation of forests should be the first step in any scheme of national planning of the country.

While contribution of forests to the nation's economy, apart from their vital role in environment, can never be underestimated, the investment in forestry sector has been rather low. For example, from the first to the sixth Five Year Plans, the investment in forestry was between 0.39 per cent and 0.71 per cent of the total plan outlay. In the seventh Five Year Plan, the allocation was raised to 1.03 per cent of the total plan outlay. But again, the investment in the forestry sector during the eighth Five Year Plan has fallen to 0.94 per cent of the total planoutlay. At present the total investment in forestry is about Rs. 800 crore against the required investment of about Rs. 3,000 crore. This is too small an investment and unless it is increased, it will not be possible to ensure sustainable supply of goods and services for the huge sector of population dependent on forests.

We have failed to realise the fact that destruction of forests is an irreversible process. The rate of afforestation has barely crawled to the 2 million hectare mark, falling short of the target set by the National Wasteland Development Board of at least 3.5 million hectare mark every year till 2010 A.D.

The forest (Conservation) Act, 1980 enacted to check indiscriminate deforestation/diversion of forest lands was amended in 1988 to make it more stringent by prescribing punishment for violations. Guidelines have been prepared for working plans. Some salient features are :

(i) Working plans should be up-to-date and stress conservation;

(ii) Preliminary working plan should have multi-disciplinary approach;

(iii) Tribal rights and concessions should be highlighted along with control mechanism;

(iv) Grazing should be studied in detail and specific prescriptions should cover fodder propagation;

(v) Shifting cultivation and encroachments need to be controlled;

(vi) Clear-felling with artificial regeneration should be avoided as far as possible and clear-felling blocks should not exceed 10 hectares in hills and 25 hectares area in plains and

(vii) Banning all felling about 1000 metre altitude for a few years should be considered to allow these areas to recover. Critical areas in hills and catchment areas prone to landslides, erosion, etc. should be totally protected and quickly afforested.

The Indian Council of Forestry Research and Education (ICFRE) was created in 1987 under the Central Ministry of Environment and Forests. Later on it was constituted into an autonomous body on the pattern of the Indian Council of Agricultural Research with its headquarter at Dehra Dun. Following forestry research institutions are working under this organisation:

(i) Forest Research Institute, Dehradun,

(ii) Institute of Arid Zone Forestry Research, Jodhpur,

(iii) Institute of Rain and Moist Deciduous Forests, Jorhat,

(iv) Institute of Wood Science and Technology, Bangalore,

(v) Tropical Forestry Research Institute, Jabalpur,

(vi) Institute of Forest Genetics and Tree Breeding, Coimbatore

(vii) Temperate Forest Research Centre, Shimla

(viii) Centre for Forest Productivity, Ranchi and

(ix) Centre for Social Forestry and Environment, Allahabad.

The future welfare and prosperity of India would very much depend upon our ability, effort and success in conserving, developing and proper utilisation of our forest resources. It is, therefore, high time that the nation as a whole awakens to this burning problem for the sake of a better future.

PRESERVATION OF WILDLIFE

The fast dwindling forest cover in India has adversely affected wildlife in the country. The number of several species has been drastically reduced, some are endangered species, the others are on the verge of extinction while some of them have already disappeared. This is a very serious trend and will disturb the ecological balance. Therefore, it must be checked and reversed at all costs. This calls for urgent measures for preserving wildlife.

Indian Board for Wild life was constituted in 1952. The main purpose of the board was to advise the Government on the means of conservation and protection of wildlife, construction of national parks, sanctuaries and zoological gardens as well as promoting public awareness regarding conservation of wildlife. The wildlife (protection) Act, 1972 is a comprehensive law which gives firm status to the national parks and sanctuaries and other game reserves, extends statutory safeguards to the entire geographical area, prescribes potent control over the trade and traffic in wild animals and animal articles laying down deterrent punishment for the miscreants. This act has been amended to make the provision more effective. Endangered species of plants and animals have been brought under the purview of this act.

Project Tiger, one of the premier conservation efforts in the country was launched in April, 1973. It is a centrally financial scheme under which 21 Tiger Reserves have been set up. The project has achieved great success in preserving the tiger. It is estimated that there were about 40,000 tigers in India in the beginning of the twentieth century which were reduced to 4,000 *i.e.*, one tenth in 1965. The figure further slid to a near extinction level of 1875 in 1972. As a result of the tiger project the tiger population is now well over 3,000. A Tiger crisis cell has also been formed in the Ministry of Environment and Forests.

The National Wildlife Action Plan adopted in 1983 provides the framework and programme for conservation of wildlife. At present the protected area network comprises 80 national parks and 441 sanctuaries covering 4.5 per cent of the total geographical area of the country.

A Central Zoo Authority has been set up for the proper management of Zoological parks in the country. It coordinates the activities of over 200 zoos and also supervises the exchange of animals.

As in case of forests, the central government is very keen to preserve wildlife and provides financial and technical assistance to states for:

(i) Development and improved management of national parks;

(ii) Protection of wildlife and control of illegal trade in wildlife products;

(iii) Eco-development in areas around national parks, and sanctuaries;

(iv) Conservation of elephant and its habitat, and

(v) Conservation of rhinos in Assam.

WILDLIFE

Wildlife comprises animals, birds, and insects living in forests. With large regional variations in physiography, climate and edaphic types, Indian forests offer a wide range of habitat types which is responsible for a large variety of wild life in India. There are about 76,000 species of animals in India which is about 82 per cent of the known living species of the world. India boasts of over two thousand species of birds, over five hundred species of mammals and several hundred species of reptiles and amphibians.

Elephant is the largest Indian mammal which only a few centuries ago, was found in large numbers in vast forest tracts of India. There are bout 6000 elephants in the forests of Assam and West Bengal, about 2,000 in Central India and nearly 6,000 in three southern states of Karnataka, Kerala and Tamil Nadu. The one-horned *rhinoceros*, India's second largest mammal was once found throughout the Indo-Gangatic Plain as far west as Rajasthan. The number of this mammal has drastically decreased and now there are less than 1,500 rhinoceros in India, confined to the restricted locations in Assam and West Bengal. They survive under strict protection in the *Kaziranga* and *Manas* sanctuaries of Assam and the Jaldapara sanctuary of West Bengal. The arna or wild buffalo is found in Assam and in Bastar district of Madhya Pradesh. The gaur or the Indian bison is one of the largest existing bovine and is found in the forests of Central India. There are about 3,000 tigers in India mainly found in the forests of eastern Himalyan foothills and in parts of the peninsular India. The number of Cheetahs had fallen to less than two hundred until successful breeding programme in the Gir sanctuary in Gujarat resulted in some recovery. The arboreal clouded leopard is found in northern Assam while the black Panther is widely distributed predator. *Desert* and *jungle* cats live in north western parts of the country. Lynx live upto 3010 m. in Ladakh. *Brown, Black* and *Sloth Bear* are found at high altitudes in the north-western and central Himalayas.

Yak, the ox of snows is largely found in Ladakh and is tamed to be used as a draught animal. Several species of wild sheep and wild goats are also found in India. The *shapu* or *urial, bhoral* the blue sheep, and *nayan,* a huge sheep with curved horns are the main types of sheep. Serow and goral are the goat antelopes of the Himalayas. The Kashmir markhar, the ibex and the Himalayan thar are some of the Himalayan wild goats.

Deer also used to roam widely across the Indian forests, although their number has been drastically reduced. Stag or barasingha, is found in Assam and/Madhya Pradesh. The Munjac or barking deer are found extensively in the lower wooded slopes of the Himalayas and in the forests of southern India. The kastura or the musk deer, much sought after for its musk pod, live in the birch woods in the higher forests of the Himalayas. Thamin is a pretty deer found in Manipur.

Several species of *monkeys* are found in almost all the forest areas of India, the two commonest being the Rhesus Macaque and the Common Langur. There are wide regional variations in the body structure and behaviour of monkeys in India.

The Chinkara or the Indian gazelle, the black buck or the Indian antelope, the nilgai or the blue bull, the mouse deer or the Indian chevrotain, the *chawsinga* or the four horned antelope, wild dog, the fox, the jackal, the hyena, the mongoose, shrews, hedgehogs, mole, bats, rodents and squirrels are the other mammals found in the Indian forests.

India also abounds to large variety of reptiles, although many of them are now endangered species. There are more than 200 species or subspecies of snakes, the best known being the *Cobra, Krait* and *Russel Viper*. These are poisonous snakes while Dhaman is a non-poisonous large snake. The length of the King Cobras may be well over five metres which makes him the longest poisonous snake. However, the Rock Python and the Reticulated Python may be seven metres long, weighing over 115 kg. Several snakes living in water are also poisonous, although many of them Tare non-poisonous. The Blunt Nosed or Marsh Crocodile (the *Magar* or *Mugger*) and the long nosed *Gharial* are important large sized reptiles, although their number has drastically reduced. They are hunted for their skins which fetch handsome price. The big Estuarine Crocodile is still found from the Ganges to the Mahanadi. The Lizards include well known Chameleon and the monitor lizard or varanus. They are found in both deserts and forests but are endangered species. India has some important breeding beaches for a number of species of turtle. In Orissa about 3,00,000 Olive Ridley Turtles breed while Hawksbill Turtles breed in southern Tamil Nadu.

India is extremely rich in bird life. There are about 2,000 species of birds in India which is about three times the number of species found in Europe. Although most of the birds have their origin in India, a number of them have their source in other areas. Some birds such as ducks, cranes, swallows, and fly-catchers migrate from central Asia to the wetlands of Bharatpur every winter. Recently, some migratory birds have been seen near Mathura.

Indian bird-life has all the varieties of the birds including aquatic, gallinaceous and orboreal birds. Aquatic birds include a large variety of storks, herons, ducks, flamingoes, egrets and cormorants. Among the waders and shore birds are the snipes, iluses, gulls, cranes and the lapwings. The Great Indian Bustard, pea fowl, jungle fowl, quail and partridge are the main ground birds. Babblers, babbits, bulbuls, mynas, pigeons, parakeets, doves, cuckoos, rollers, beaters, flycatchers, orioles, warblers, wagtails, finchlarks, finches, drongos, hoops, etc. are other important birds. India is the home of a number of birds of prey, the important being owl, eagle, kite, falcon, kestrel, etc. Peacock is the national bird of India. Its magnificent plumage symbolizes the colour and wealth of India's bird life.

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7

DROUGHTS AND FLOODS

INTRODUCTION

The uncertainty and unreliability of Indian rainfall leads to problems of *droughts* and *floods*. The rainfall, mainly by the south-west monsoons, may be either below normal or it may be above normal. Droughts occur in the event of scarce rainfall while heavy rainfall results in floods. *As a matter of fact, droughts and floods are two extreme ends of the hydrologic cycle.* Droughts affect particularly the areas of low amount of rainfall and high rainfall variability. Droughts and floods result in crop failure and famines are the natural outcome. *Of all the natural calamaties, droughts and floods have affected the Indian masses the most.* Droughts and .floods are recurring diasters in India and one part of the country or the other has to face famine almost every year either due to droughts or due to floods. This leads to a chain of miseries especially for the poor people who live just on subsistence level. In any famine, the worst hit are the landless labourers. When the rains fail, their labour is no longer required on the land. They are first to feel the economic pinch and having little or no property or possessions are soonest brought to destitution and starvation. Every year large number of people suffer from hunger and malnutrition and many of them die of starvation.

DROUGHTS

Droughts in India occur in the event of a weak south-west monsoon. A weak monsoon results in deficient rainfall and droughts occur. Droughts also occur due to late arrival or early withdrawal of the monsoons. Prolonged breaks in the monsoon during rainy season also result in droughts. Although a drought may occur at any time and in any part of the country, most of the drought prone areas are those having marginal rainfall and high variability of rainfall.

In India, the hard core of recurring drought affects 16 per cent of the total area and 12 per cent of the population, although the total average drought prone area may be as much as 10 lakh sq. km. or about one third of the total land area of the country.

The areas regularly haunted by droughts are those receiving low (generally below 75 cm. annually) and highly unreliable (variability over 40 per cent) rainfall and with inadequate irrigation facilities. In all 77 districts receiving less than 75 cm. of rainfall per annum are drought prone. This accounts for 34 per cent of the net sown area.

In addition, there are 22 districts in Maharashtra, Gujarat, Madhya Pradesh, Karnataka, Rajasthan and Uttar Pradesh accounting for 9 per cent of the cultivated area of the country which receives 75 to 85 cm. of rainfall per annum. This rainfall is of doubtful efficacy and as such these districts should also be considered vulnerable to drought. However, the severest droughts have occurred in comparatively wet areas such as West Bengal, Bihar and Orissa where rainfall is normally plentiful enough to allow high density of population and where failure of rainfall can affect millions of people.

There are some well defined tracts of drought which are briefly described as under: (Fig. 7.1).

(a) The desert and semidesert regions covering about 6 lakh sq. km. It is more or less a rectangle formed by lines from Ahmedabad to Kanpur on one side and from Kanpur to Jalandhar on the other. Some areas in this region are without irrigation and comprise the worst famine tracts of the country.

(b) The dry region lying in the leeside of the Western Ghats upto a width of 300 kms. stretching eastwards up to 100 kms. from the East Coast and reaching right upto the southern tip of the peninsula. It covers an area of about 3.7 lakh sq. km.

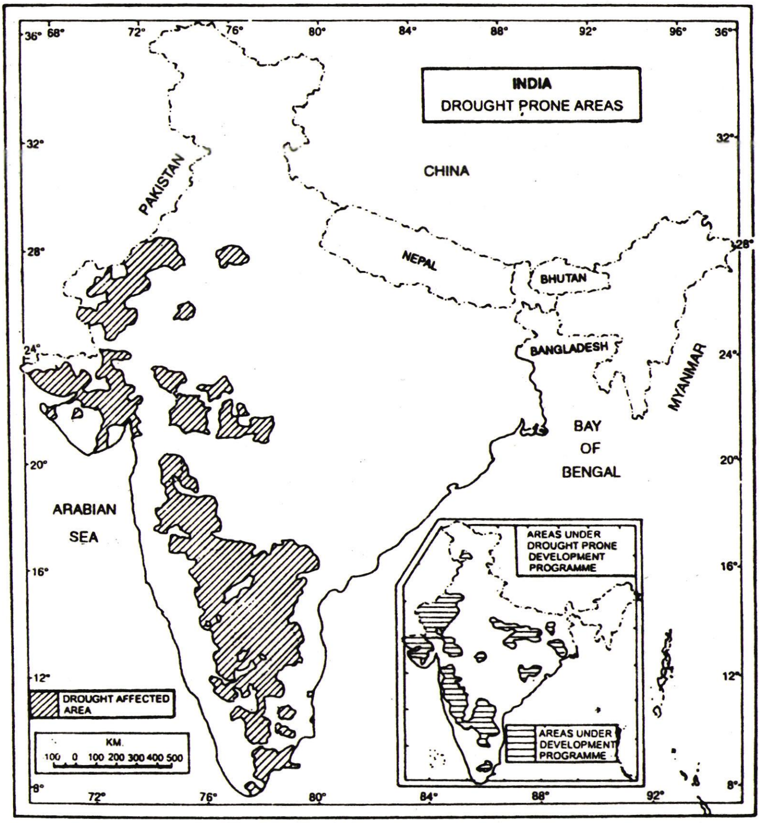
INDIA
DROUGHT PRONE AREAS
CHINA
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
MYANMAR
BAY OF BENGAL
ARABIAN SEA
DROUGHT AFFECTED AREA
KM
100 0 100 200 300 400 500
AREAS UNDER DROUGHT PRONE DEVELOPMENT PROGRAMME
AREAS UNDER DEVELOPMENT PROGRAMME
36° 68° 72° 76° 80° 84° 88° 92° 96° 36°
32° 28° 24° 20° 16° 12° 8°

Fig. 7.1 : Drought Prone Areas.

(c) Outside the above mentioned two major regions, there are isolated pockets which experience frequent droughts and are termed as drought prone areas. They are :

(i) Coimbatore and Nellai Kottabomman districts in Tamil Nadu;

(ii) Sourashtra and Kuchchh regions;

(iii) Jhansi, Lalitpur, Banda and Mirzapur districts of Uttar Pradesh;

(iv) Palamau plateau of Bihar;

(v) Purulia district of West Bengal; and

(vi) Kalahandi region of Orissa. These scattered pockets account for about one lakh sq. km.

There had been 23 drought years from 1877 to 1987 giving an average of one drought year in every five years. Out of the 23 drought years 5 were slight, 13 moderate, 2 severe and 3 calamitous. The worst droughts were in 1877, 1899 and 1918 when over sixty per cent of the total land area of the country faced acute shortage of rain water and consequent shortfall in agricultural production resulting in famine conditions. The drought of 1918 was the most calamitous in the recorded history of droughts in India when over two - thirds of the total land area faced acute distress. It affected large parts of East Uttar Pradesh, West Uttar Pradesh, Haryana, Punjab, Himachal Pradesh, Rajasthan, West Madhya Pradesh, Saurashtra, Kuchchh, Maharashtra, Telanganga, Rayalaseema and Jammu and Kashmir. In the recent years, drought of 1987 has been very severe when about half of India was without sufficient rain. According to India Meteorological Department (IMD), 25 out of 35 meteorological divisions received scanty or deficient rainfall. According to agricultural ministry sources, of the 470 districts in the country only 145, that is about 30 percent had adequate rainfall, 150 received scanty rain, in 110 districts there was no rain or it was meagre. The worst hit areas were Kuchchh, Andhra Pradesh, Haryana, Madhya Pradesh, Himachal Pradesh, Jammu and Kashmir, Maharashtra, Kerala, Orissa, Punjab, Uttar Pradesh and Rajasthan. The drought conditions in different parts of the country resulted in a shortfall of 100-200 lakh tonnes in the production of foodgrains. Thousands of cattle perished due to shortage of fodder and water.

Although, droughts do occur at frequent intervals and their frequency is likely to increase in future due to ecological imbalances their capacity to kill large number of human beings and animals have been considerably reduced, thanks to efficient means of transportation, buffer stocks of foodgrains and aid programmes of central and state governments as well as those of voluntary organisation. After the disastrous draught and crop failure in 1965-66, the India Meteorological Department, as per recommendations of the Planning Commission, set up a 'Drought Research Unit' to describe and understand the climatology of drought. This unit has been functioning since 1967.

Drought Prone Areas Programme (DPAP) was initiated in 1973 as an integrated area development programme. The programme was conceived as a long term measure for restoration of ecological balance by conserving, developing and harvesting land, water, livestock and human resources. The objectives of the programme are:

(i) To minimise the adverse effects of drought on production of crops and livestock and productivity of land, water and human resources through integrated development of the natural resources base of the area and adoption of appropriate technologies.

(ii) To conserve, develop and harness land, water and other natural resources including rainfall for restoration of ecological balance in the long run.

DPAP is under implementation in 629 blocks of 96 districts in 13 states. The total area covered under this programme is about 5.54 lakh sq. km.

The best way to fight the menace of drought on the agricultural front is to provide proper irrigation facilities. This has been amply illustrated by the experience of Punjab, Haryana and Western Uttar Pradesh which were highly precarious tracts, frequently affected by famine before they were provided with irrigation.

FLOODS

Floods comprise another natural calamity which India has to face almost every year. Floods are caused by excessive rainfall by the south-west monsoons, tropical cyclones in the pre and post monsoon periods, silting of the river beds, changes in the river courses and deforestation. Sometimes, floods may occur due to bursting of a dam, such as Machhu dam in Gujarat in August, 1979.

India is so vast and physically so diverse that she has experienced more floods than any other part of the world. Out of total 329 million hectares of geographical area 40 million hectares or one-eighths of the total land area of country is assessed to be flood-prone. About 7.89 million hectares of land is flooded every year of which 3.64 million hectares constitute cropped area. About 24 million people are affected, over 1500 are killed and nearly twelve lakh houses are damaged every year by floods. Of the total damage by floods, about three-fourth is to crops and the rest is to houses and public utilities such as roads, railways and communication lines. Table 7.1 gives an idea of the extent of damage done by floods.

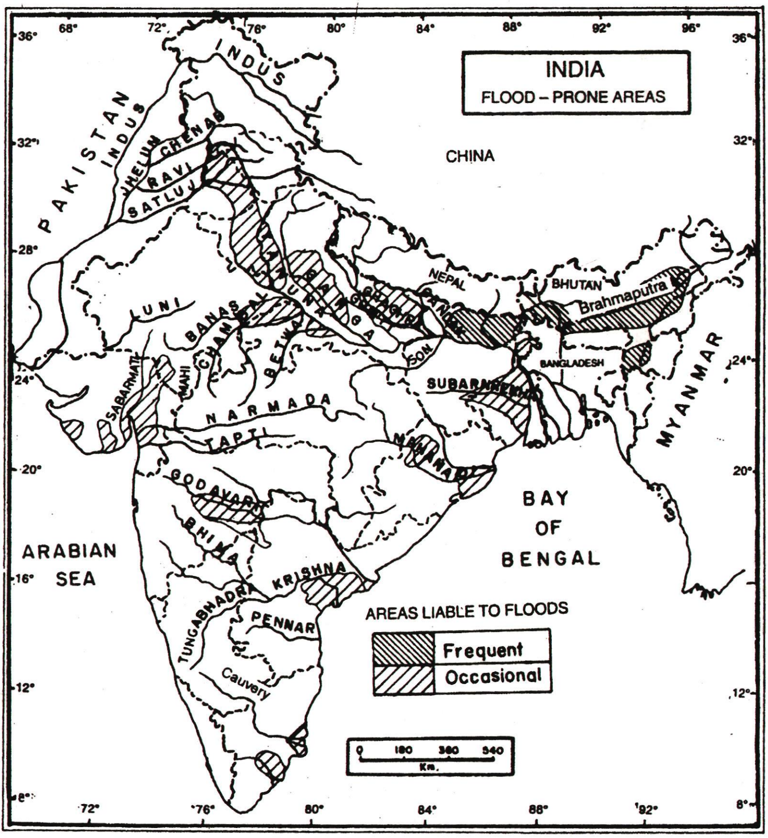
INDIA
FLOOD – PRONE AREAS
CHINA
PAKISTAN
INDUS
JHELUM
CHENAB
RAVI
SATLUJ
NEPAL
BHUTAN
Brahmaputra
BANGLADESH
MYANMAR
LUNI
BANAS
CHAMBAL
MAHI
SABARMATI
BETWA
YAMUNA
GANGA
GHAGRA
GANDAK
SON
SUBARNREKHA
NARMADA
TAPTI
MAHANADI
GODAVARI
BHIMA
KRISHNA
TUNGABHADRA
PENNAR
Cauvery
ARABIAN SEA
BAY OF BENGAL
AREAS LIABLE TO FLOODS
Frequent
Occasional
0 180 360 540
Km.
36°
32°
28°
24°
20°
16°
12°
8°
68°
72°
76°
80°
84°
88°
92°
96°

Fig. 7.2 : India—Flood Prone Areas.

Table 7.1 : Statement showing maximum and average flood damage, 1953-1989

	Nature of damage	*Maximum*	*Year*	*Average*
1.	Area affected (in million hectares)	17.53	1978	7.89
2.	Population affected (in million)	70.45	1978	32.65
3.	Cropped area (in million hectares)	10.14	1988	3.64
4.	Volue of crops damaged (Rs. in crores)	2510.90	1988	441.60
5.	Number of houses damaged (in thousands)	3567.542	1978	1223.856
6.	Value of houses damaged (Rs. in crores)	741.6	1988	130.58
7.	Numbers of cattle heads lost	618248	1979	162058
8.	Number of human lives lost	11316	1977	1523
9.	Damage to public utilities (Rs. in crores)	2050.04	1985	343.85

Source : A. K. Chatterji, Monsoons, Cyclones and Floods in India, pp. 47-52.

A glance at figure 6.2 will show how the flood prone areas are distributed. It is estimated that over three-fourth of the total damage done to crops and property is in the plains of Northern India comprising of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal and Assam. In the Punjab-Haryana Plain heavy rainfall in the waterlogged and poorly drained areas inundate large parts. Major and minor rivers like the Satluj, the Beas, the Ghaggar and the Markanda are in spate during the rainy season and bring flood havoc to vast areas. About 15 per cent of the total flood damage in the country is borne by this plain.

In Uttar Pradesh and Bihar, the mighty Ganga receives a large number of tributaries such as the Gomati, the Ghaghara, the Gandak and the Kosi from the left as well as the Yamuna and the Son from the right. This brings huge quantities of water to these areas both from the Himalayan region and from the Peninsular India resulting in devastating floods. River Kosi often shifts its course flooding new areas and converting once fertile areas into wasteland. The Yamuna is an important right bank tributary of the Ganga and floods large areas in Uttar Pradesh and Haryana. The Chambal and the Betwa meet the Yamuna and add to the flooding capacity of the Yamuna. On an average, 33 per cent of the flood damages in India are accounted for by Uttar Pradesh and 27 per cent by Bihar. In West Bengal the Ganga delta and the courses of Tista and Torra are often flooded. There are occasional floods caused by the Damodar river even after the construction of four dams and a barrage under the Damodar Valley Project. In 1956, about 25,000 sq. km. of area was flooded in Southern districts of West Bengal by this river.

In Assam, the floods are caused by the Brahmaputra and its tributaries like the Dihang and the Luhit. In the Brahmaputra basin, floods are almost an annual feature. The main cause of floods here is heavy rainfall amounting over 250 cm. during the rainy season. Large amount of silt is deposited here by the Brahmaputra and its tributaries which makes the river channel shallow and its capacity to carry large amount of water is reduced. This results in flooding of the vast areas in and around the valley.

Earthquakes, which occur at frequent intervals, cause change the level of river course and the flow of water in the river is obstructed. This leads to inundation of large areas in this region. Landslides are very common here. Huge rock material falling as a result of landslides acts as a temporary dam across the river and vast area is submerged under water. Later it gives way under the pressure of water and floods large area downstream. The Assam Valley is considered to be one of the worst flood-affected areas of India.

In the north-western river basin covering Jammu and Kashmir and Himachal Pradesh, the Satluj, the Beas, the Ravi and the Chenab often flood large areas. Even the drier parts of the country such as Rajasthan and Gujarat, which were earlier considered to be free from floods, have experienced floods during the recent years.

In the Peninsular India, the deltas of the Mahanadi, the Godavari, the Krishna and the Cauvery suffer from occasional floods owing to the large scale silting and the consequent change in the river courses. Indiscriminate felling of trees in the catchment areas of major rivers has complicated the flood problem.

High tide at the time of flood aggravates the flood situation. Even the construction of Hirakund dam across the Mahanadi has not made the lower area absolutely free from flood. The flood of August-September 1960 is an eye opener. Lower courses of the Narmada and the Tapi are also prone to floods.

It is worth mentioning that the floods in southern India are not as frequent as they are in the northern parts of the country and generally speaking the flood problem is not so serious there. But wherever they occur, they often exceed those in other regions and cause heavy damage to the life and property. In the plateau region of Central India, the floods are less frequent and far less destructive due to scarcity of rainfall and comparatively less load carried by the rivers.

FLOOD CONTROL PROGRAMMES AND POLICY

After devastating floods in 1954, the Government of India announced a National Flood Management Programme. The programme was divided into three phases—immediate, short-term and long term.

(a) *Immediate phase* extending over a period of 2 years was adopted for intensive collection of data and execution of emergent flood protection measures.

(b) *Short-term measure* covering next 4 to 5 years, included construction of spurs and embankments at selected sites.

(c) *Long-term measures* included the construction of storages, reservoirs on rivers/tributaries and additional embankments.

It has been estimated that out of 40 million hectares only 32 million hectares can be provided with reasonable degree of flood protection by structural measures.

Since the launching of the National Flood Control Programme in 1954, nearly, 14,432 million hectares of land has been provided with reasonable degree of flood protection. About 16,199 km. of embankments, 32,003 km. of drainage channels, 906 town-protection works and raising the level of about 4721 villages had been completed upto March, 1994. These achievements have been executed at an expenditure of Rs. 3860.4 crore.

Besides a number of reservoir projects have been completed which have helped in mitigating flood-peak in the down stream reaches. Notable among these are Tilaiya, Konar, Maithon and Panchet Hill dams in the Damodar Valley System, Bhakra Dam on the Satluj, Hirakund Dam on the Mahanadi, Pong Dam on the Beas, Nagarjun Sagar and Tunghbhadra on the Krishna and Ukai Dam on the Tapi. All these dams have afforded reasonable degree of protection to about 13.64 lakh hectares of land. In case of flood prone river scheme till the end of 1994-95 an area of 6.85 lakh hectare out of the treatable area of 75.6 lakh hectare has been treated.

FLOOD FORECASTING

Flood forecasting involves giving prior information regarding the occurrence of floods. This is essential and is extremely useful for taking timely action to prevent loss of human lives, livestock and movable property. The Central Water Commission (CWC) started flood forecasting in 1958 when the first forecasting station was established at Old Railway Bridge, Delhi. Since then it has been extended to cover almost all the major inter-state flood prone rivers of the country. At present, the Flood Forecasting Network comprises about 300 Flood Forecasting Stations spread over 66 river basins covering most of the inter-state rivers of the country. Over four thousand flood forecasts are issued every year, over 95 per cent of them are within the prescribed limit of accuracy.

A Memorandum of Understanding was signed by India and Nepal in 1988 according to which 45 Hydrological and Hydrometeorological Stations were to be set up in India and Nepal for issuing flood forecasts to benefit both the countries.

Flood forecasting techniques are being constantly reviewed, uptdated and modernised to make forecasts more accurate. This includes VHP telemetry system in Upper Yamuna basin, use of data received from INSAT-2B, computerised mathematical models for forecast formulations and computerised 'Rood Forecasting and Warning Performance Appraisal System' (FFWNPAS) etc. A pilot project on the Yamuna was taken up with the assistance of the United Nations Development Programme (UNDP) in the year 1980. Fourteen data collection-cum-auto-reporting stations, which were provided with sensors for measuring precipitation, temperature and water level were installed. The data from these 14 stations are automatically collected and transmitted through a VHP link to the central station located at CWC Headquarters, New Delhi where a Master Teleprocessor has been installed interfaced with mini-computer H.P. 1000. All the 14 reporting stations have now been hooked to INSAT series of satellite for better results. These developments have considerably reduced the miseries suffered by man from recurring floods.

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8

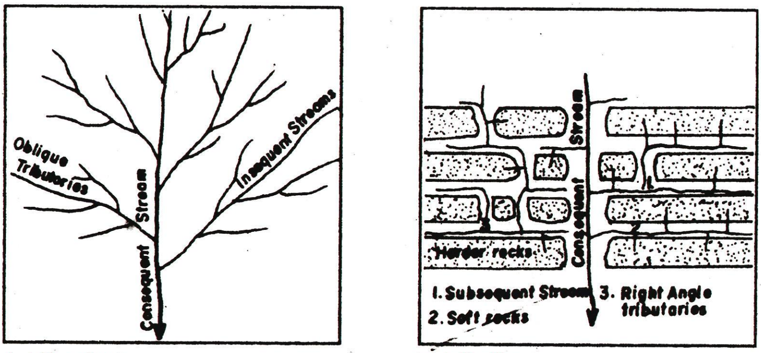
DRAINAGE

INTRODUCTION

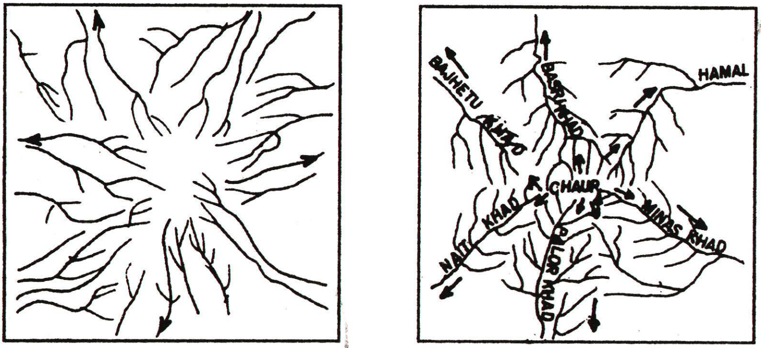
The term 'drainage' is used to describe the river system of an area. Look at any physical map. You will notice than small streams flowing from different directions come together to form the main river, which ultimately drains into a large water body such as a lake or a sea or an ocean. The area drained by a single river system is called a *drainage basin* or a river basin. On a closer observation of the map, you will notice that any higher ground, such as a mountain or an upland, separates two adjoining drainage basins. Such an upland is known as a watershed or a *water divide*.

It is Interesting to note the arrangement streams within a drainage basin. Depending upon the relief, geological structure and climatic conditions of the area, the streams form different patterns *e.g.*, dendritic, *trellis* and *radial* even within one river basin. As the name suggests a *dendritic pattern* consists of a single main stream with tributaries resembling the branches, of a tree. A long river joined by short flowing streams, approximately at right angles, makes a rectangular pattern called *trellis*. In a radial pattern, the streams flow in different directions from a central peak or domelike structure.

With this background, we can understand the drainage of India better. Drainage is an outcome of the evolutionary process of the broad relief features of the country. On the basis of the origin, the river systems of India may be classified into, two groups :


Oblique Tributaries
Consequent Stream
Insequent Streams
Consequent Stream
Harder rocks
1. Subsequent Stream
2. Soft rocks
3. Right Angle tributaries

(a) Dendritic (b) Trellis


BAJHETU KHAD
BASRI KHAD
HAMAL
CHAUR
NAIT KHAD
MINAS KHAD
PALOR KHAD

(c) Radial (d) A part of Yamuna Basin

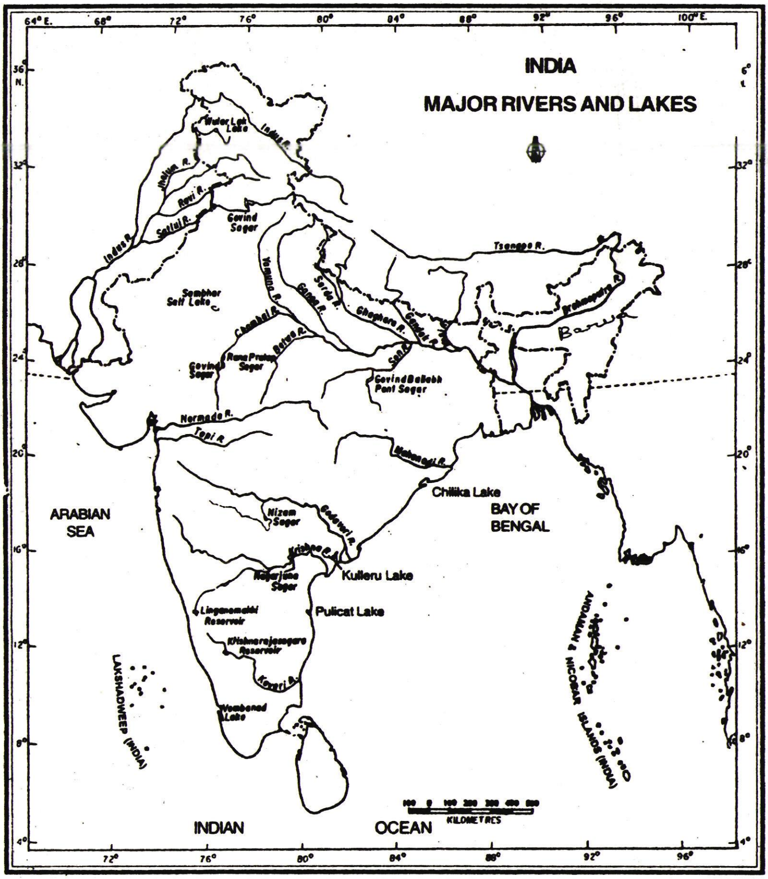
Fig. 8.1 : Drainage patterns (a) Dendritic (b) Trellis (c) Radial (d) Girl Basin, a tributary of river Yamuna.

(i) The Himalayan rivers, and

(ii) The Peninsular rivers.

There are significant differences between the two groups of rivers. The Himalayan rivers have large basins. Many rivers pass through the Himalayas and have made spectacular gorges. These deep valleys with steep rock sides were formed by the down cutting of the river during the period of the Himalayan uplift. These rivers are perennial because they get water from the rainfall as well as the melting of ice. They perform intensive erosional activity up the streams and carry huge load of sand

and silt in the plains, they form large meantiers, and a variety of depositional features like Hood plains, river cliffs and levee.


INDIA
MAJOR RIVERS AND LAKES
Wular Lake
Indus R.
Jhelum R.
Ravi R.
Satluj R.
Indus R.
Govind Sagar
Sambhar Salt Lake
Yamuna R.
Sarda R.
Ganga R.
Ghaghara R.
Gandak R.
Tsangpo R.
Brahmaputra R.
Chambal R.
Rana Pratap Sagar
Betwa R.
Gandhi Sagar
Son R.
Govind Ballabh Pant Sagar
Narmada R.
Tapi R.
Mahanadi R.
Chilika Lake
BAY OF BENGAL
ARABIAN SEA
Nizam Sagar
Godavari R.
Krishna R.
Nagarjuna Sagar
Kulleru Lake
Pulicat Lake
Linganamakki Reservoir
Krishnarajasagara Reservoir
Kaveri R.
Vembanad Lake
LAKSHADWEEP (INDIA)
ANDAMAN & NICOBAR ISLANDS (INDIA)
INDIAN
OCEAN
KILOMETRES
64° E.
68°
72°
76°
80°
84°
88°
92°
96°
100° E.
36° N.
32°
28°
24°
20°
16°
12°
8°
4°

Based upon Survey of India map with the permission of Surveyor General of India. The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line. Responsibility for correctness of internal details shown on the map rests with the publisher.

Fig. 8.2 : Major rivers and lakes of India.

The Peninsular rivers flow through shallow valleys. A large number of them are seasonal as their flow is dependent on rainfall. During summer even the large rivers have highly reduced flow of water in their channels. The Intensity of erosional activity is also comparatively less because of the gentler slope. The hard rock bed and lack of silt and sand does not allow any significant meandering. Many rivers, therefore, have straight and linear courses. In other words in, India is blessed with hundreds of large and small rivers which drain the length and breadth of the country. Rivers constitute the most useful natural resource. They have attracted the attention of planners, economists, geographers, geologists, hydrologist and a host of other specialists from different fields. They are a great source of water for irrigation, industry and domestic purpose and offer innumerable sites for producing hydroelectricity. Almost all the fertile areas of the country have been formed by the depositional work of rivers. Many rivers are used as channels for inland water transport. Fishing has become an important occupation along the rivers courses.

In all India receives an annual average rainfall of 118 cm. which provides 3,645,480 million cubic metres of water. Of this, about 1,250,480 million cubic metres or 34.3 per cent goes back to atmosphere due to evaporation and roughly 750,000 million cubic metres or 20.6 per cent seeps into the soil, leaving about 1,645,000 million cubic metres or 45.1 per cent to flow into the river systems.

THE DRAINAGE SYSTEMS OF INDIA

On the basis of their size, rivers of India can be classified in the following three categories:

(i) *Major river basins* with catchment area of 20,000 sq. km. and above account for 85 per cent of the total run-off of all the rivers of India. They are fourteen in all and are in high rainfall areas (*i.e.* 63 million cubic metre per 100 sq. km). There are three river systems to the north of Tropic of Cancer, Severn between Tropic of Cancer and 20°N latitude and four in the Peninsular India.

(ii) *Medium river basins* with a catchment area between 2,000 sq. kms. and 20,000 sq. kms. account for 7% of the total run off of all the rivers. They are 44 in all and have medium rainfall (*i.e.* 45 million cubic metres per 100 sq. km.)

(iii) *Minor river basins* with a catchment area below 2,000 sq. km. account for 8 per cent of the total run off of all the rivers of India. There are large number of such rivers. They are located either in dry areas or in the coastal areas, especially on west coast where the rivers are much shorter due to narrow coastal plain between the coast and the western ghats.

Depending upon the origin of rivers two broad drainage systems of India are generally recognised :

(a) The Himalayan rivers including the Indus, the Ganga, the Brahmaputra and their tributaries, and

(b) The Peninsular rivers which include along with their tributaries, a large number of rivers such as the Mahanadi, the Godavari, the Krishna, the Cauvery, the Narmada and the Tapi.

Over 90 per cent of the water carried by the Indian rivers is housed into the Bay of Bengal; the rest is drained into the Arabian Sea or forms inland drainage. This lop sided distribution is due to the location of the watershed separating the drainage systems falling into the Bay of Bengal and the Arabian Sea. This 2736 km. long watershed runs from Kanniyakumari through the Western Ghats, the Ajanta, the Maikala, the Vindhayas and the Aravalis ranges to the Shiwalik hills near Haridwar

THE HIMALAYAN RIVER SYSTEMS

Three Major river systems viz. the Indus, the Ganga and the Brahmaputra comprise the Himalayan river systems. Many of the Himalayan rivers existed even before the Himalayan ranges were uplifted. These rivers originate in the Tibetan side beyond the mountain ranges of the Himalayas. The gorges of the Indus, the Satluj, the Alaknanda, the Gandak, the Kosi and the Brahmaputra clearly indicate that these rivers are older than the mountains themselves. It is believed that they continued to flow all through the building phase of the Himalayas; their banks rising steeply while the beds went lower and lower, thus, cutting deep gorges through the rising Himalayan ranges. Thus, the Himalayan rivers are typical examples of *antecedent drainage*. The evolution and flow of the Himalayan rivers is described as under:

EVOLUTION OF THE HIMALAYAN RIVERS

Some of the unwarranted features of the Himalayan rivers such as the longitudinal courses of the Indus, the Satluj and the Brahmaputra; deep gorges cut by the rivers across the Himalaya; and still westerly flowing tributaries in their upper reaches are a great puzzle and require proper explanation. This has been partly done by assuming a mighty river which flowed from Assam to Punjab and even beyond upto Sind. This hypothetical ancient river was called the *Indo-Brahm* by E.H. Pascoe who thought that the present day Indus and Brahmaputra were the severed parts of the original river. However, it was named as the *Shiwalik River* by *E.G.,* Pilgrim who considered that the course of the primitive river is occupied by the present day Shiwalik hills.

Pascoe and Pilgrim presented an elaborate and comprehensive hypothesis, independently in 1919, on the assumption that the Shiwalik deposition occurred along this great river. The river came into being due to earth movements which took place in *Tertiary times* and is believed to be successor of the *Himalayan sea.* In the Eocene Epoch a gulf extended from Sind to Afghanistan and from there extended eastward and south-eastward through Kohat and Punjab to the neighbourhood of Nainital. This gulf gave place to a great rivers. With its headwater consisting of portions of the Brahmaputra, this master stream flowed along the foot of the Himalayas first westward and then north-westward as far as north-western Punjab where it turned southward more or less along the course of the modern Indus, and emptied itself into Arabian Sea. Later, this mighty stream dismembered into the following systems and sub-systems:

(a) the Indus,

(b) the five tributaries of the indus in Punjab

(c) the Ganga and its Himalayan tributaries, and

(d) the stretch of the Brahmaputra in Assam and its Himalayan tributaries.

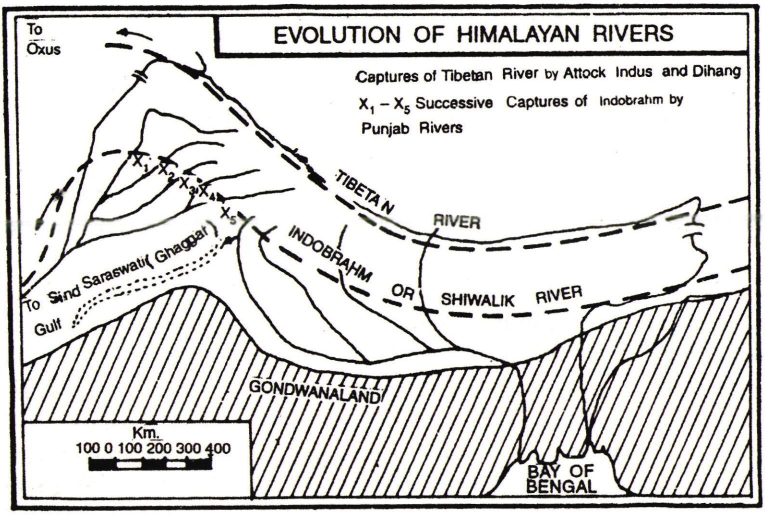

To Oxus
EVOLUTION OF HIMALAYAN RIVERS
Captures of Tibetan River by Attock Indus and Dihang
X1 – X5 Successive Captures of Indobrahm by Punjab Rivers
X1
X2
X3
X4
X5
TIBETAN RIVER
INDOBRAHM OR SHIWALIK RIVER
To Sind Saraswati(Ghaggar)
Gulf
GONDWANALAND
Km.
100 0 100 200 300 400
BAY OF BENGAL

Fig. 8.3 : Evolution of the Himalayan Rivers.

The dismemberment was the result of the following two events :

(i) Upheavals in the western Himalays including the Potwar Plateau in the Pleistocene age and

(ii) Headward erosion by the tributaries of the Indobrahma river.

As a result of the above mentioned dismemberment of the Indobrahma river, the Indus and its tributaries, the Ganga and its tributaries and the Brahmaputra and its tributaries came into being. It is supposed that the Yamuna was first a tributary of the Indus. During the late Pleistocene and early Holocene age, it joined with the Saraswati somewhere near Suratgarh and continued to flow as Ghaggar, finally joining the Indus. Some other scholars believe that it reached upto Rann of Kuchchh as an independent river . Later on, it changed its course due to tectonic disturbance along the Aravali axis and was annexed by the Ganga to become its tributary.

Poscoe also envisaged a great *'Tibetan River'* flowing north-westwards along the Tsangpo—Manasarovar Lakes—Satluj—

Gartang —Indus trough. This river might have emptied itself into the Oxus Lake, or might have debouched on to the plains by one of a number of transverse gaps such as Photu Pass. This river also was disrupted by headward erosion by Irrawaddy—Chindwin, the Meghna—Brahmaputra, the Satluj and the Indus. According to De Terra, the rivers of Karakoram and Ladakh might have flown south-eastward or eastward. Its capture in the east might have been executed by Dihang, a tributary of the Brahmaputra.

However, this theory has been challenged on the following grounds:

(i) It is not necessary to imagine a stream of the size of Indobrahma flowing all along the length of the Himalayas to explain the occurrence of the Shiwalik deposits. These could be brought down by the rivers flowing down the slopes of the Himalayas. M.S. Krishnan and N. K. N. lyngar (1940) found it difficult to accept the existence of such a mighty river on geological-physiographical grounds.

(ii) The evidence furnished by the depositional history in the Ganga delta and in the Assam does not fit well with the concept of Indobrahma stream.

(iii) The width, thickness and lithology of the Tipam sand stones of Assam which were deposited in an estuary situated so close to the source of the Indobrahma also speak against this theory.

(iv) The upper course and the source of the Satluj river also do not fit in this theory. It is fed by underground water from the Manasarovar lake and it flows in a deep canyon cut in the soft fluviated beds of Nari Khorsum. The upper course of the Satluj is distinctly arid and the river appears to be a misfit. This could be explained if it were an old outlet of the '*Tibetan River*' Pascoe argues that the Satluj captured a part of the '*Tibetan River*' and then lost again to the rejuvenated Tsangpo after the Dihang had cut back into the furrow. This argument has been rejected by many scholars.

THE INDUS RIVER SYSTEM

The Indus (Sanskrit—Sindhu, Greek—Sinthos; Latin—Sindus), along with its tributaries forms one of the largest drainage systems of the world. It is from this river that India got her name. The Indus valley has been tin cradle of one of the oldest civilizations in the world—'the Indus Valley Civilization'.

The mighty Indus rises near Manasarovar Lake from the glaciers of the Kailas Range in Western Tibet (32° N and 81° E) at an elevation of 5180 metres. Starting from its source, it flows for a distance of 257 kms. in the north west direction under the name of Singge Khabab until it is joined by the Ghar. A short distance lower down, it enters India at an elevation of 4206 m. and continues to flow in the same north-west direction between the Ladakh and the Zaskar Ranges. The gradient of the river in this course is very gentle (about 30 cm. per km.). Here it is joined by the Zaskar river. About 50 km. before Skardu, it is joined by the Shyok at an elevation of about 2700m. The *Gilgit, Gortang, Dras, Shiger, Hanza* are the other Himalayan tributaries of the Indus. After passing through a 480 km. long antecedent and very deep gorge (5181 metres at Bunji north of Nanga Parbat), it takes a sharp southerly bend and reaches Attock at an altitude of about 610 m. Here it ends its mountainuous journey and is joined by the Kabul river from Afghanistan. Thereafter it flows through the Potwar plain and crosses the Salt Range. Some of the important tributaries below Attock include the Kurram, Toch and the Zhob-Gomal. Just above Mithankot, about 805 km. from the sea, at an elevation of 79 m. the Indus receives from *Panjnad* (Panchnad), the accumulated waters of the five eastern tributaries—the Jhelum the Chenab, the Ravi, the Beas and the Satluj. The river finally empties itself into the Arabian sea, south of Karachi after forming a big delta. The total length of the Indus river from its source to its mouth is about 2880 km. out of which only 709 km. length falls in India.

The Indus has a total drainage area of 1,178,440 sq. km. out of which about 453,250 sq. km. lies in the Himalayan mountains and foothills, the rest lies in the Indus plain of India and Pakistan. As a result of partition, Indus drainage basin has been divided between India and Pakistan with major portion going to Pakistan and India has to content with only 321,290 sq. km. which is about 27.26 per cent of the total drainage area. The average annual flow of water in the Indus river is 110,450 million cubic meters at Kalabagh.

The left bank tributaries are big rivers in themselves and deserve a brief mention here.

The Jhelum rises in a spring at Verinag at an altitude of 4900 m. in the south-eastern part of the Kashmir Valley. It flows northwards from its source to Walur Lake and further down south-westwards. The river flows through the Kashmir Valley and forms a 200 m. deep defile with almost vertical walls through Pir Panjal Range below Baramula. A number of tributaries notably the Liddar, the Sind and the Pohru, which rise in Kashmir, join the main river. At Muzaffarabad, the river takes a sharp hairpin swing southward and the Kishaganga joins at on its right bank. Thereafter, it forms the India-Pakistan boundary for 170 km. and emerges at the Potwar Plateau near Mirpur. After skirting the outlying spurs of the Salt Range it debouches on the plains near the city of Jhelum about 402 km. from its source. About 322 km. lower, it joins the Chenab at Trimmu. The river is navigable for about 160 km. out of a total length of 724 km. The average annual flow of water in the river at Mangia is 27,890 million cubic metre. The catchment area upto the Indo-Pakistan border is 34,775 sq. km.

The *Chenab* originates from near the Bara Lacha Pass in the Lahul-Spiti part of the Zaskar Range. Two small streams on opposite sides of the pass, namely *Chandra* and *Bhaga*, form its headwaters at an altitude of 4900 m. The united stream, called the Chandrabhaga flows in the north-west direction through the Pangi valley, parallel to the Pir Panjal range, and enters Jammu and Kashmir as the Chenab river at an elevation of 1838 m. Near Kistwar, it cuts a deep gorge, sometimes 1000 m. deep. Here, it flows for 290 km. between steep cliffs of high mountain and turns southwards and flows in this direction for a short distance. Further, it turns to the west and enters the plain area near Akhnor in Jammu and Kashmir after traversing a distance of about 330 km. From here it swings to the south-west through the plains of Pakistani Punjab for a distance of

644 km. to reach Panchnad where it joins the Satluj after receiving the waters of Jhelum and Ravi rivers. The total length of the river is 1180 km. Its catchment area upto the Indo-Pakistan border is 26,155 sq. km. Its annual flow at Marala is 29,000 million cubic metres.

The *Ravi* has its source in the Kullu hills near the Rohtang Pass in Himachal Pradesh. Flowing in the northwest direction from its source, it drains the area between the Pir Panjal and the Dhaola Dhar ranges. After crossing Chamba, it takes a south-westerly turn and cuts a deep gorge in the Dhaola Dhar range. It enters Punjab Plains near Madhopur and later enters Pakistan 26 km. below Amritsar. It detouches into the Chenab a little above Rangpur in Pakistani Punjab after flowing for, a distance of 725 km. from its source. Its total catchment area is 14,442 sq. kms. of which only 5,957 sq. km. lies in India. The annual flow of water in this river at Madhopur is 8000 million cubic meters.

The *Beas* originates near the Rohtang Pass, at a height of 4062 m. above sea level, on the southern end of the Pir Panjal Range, close to the source of the Ravi. Fairly steep in its upper portion (24 metres per km) it crosses the Dhaola Dhar range through a deep gorge 900 m. deep from Lorji to Talwara. On meeting the Shiwalik hills the river sweeps sharply northward, then bending round the base of the hills it takes a southerly direction and debouches on the plain near Pong. Thereafter, it takes a south-westerly direction and meets the Satluj river at Harike. It is a comparatively small river which is only 460 km. long but lies entirely within the Indian territory. Its total catchment area is 20,303 sq. km. The river carries about 15,800 million cubic metres of water at Mandi. The Satluj rises from the Manasarovar-Rakas Lakes near Darma Pass in western Tibet at a height of 4570 m. within 80 km. of the source of the Indus. Like the Indus, it takes a north-westerly course upto the Shipki La pass on the Tibet-Himachal Pradesh boundary. Here the river flows at an altitude of an about 3,000 m. above sea level. It cuts deep gorges where it pierces the Great Himalaya and the other Himalayan ranges. In Nari Khorsan province of Tibet, it has created an extraordinary canyon, comparable to the Grand Conyon of Colorado; the channel here is 900 m. deep.

Its tributaries in Himachal Pradesh are short in length except the Spiti, which drains a large trans-Himalayan area and joins it at Namgia near the Shipki pass. Before entering the Punjab plain, it cuts a gorge in Naina Devi Dhar, where the famous Bhakhra dam has been constructed.

Table 8.1 : The Indus Drainage System

Name of the river	*Source*	*Length in km.*	*Area drained (sq. km.)*	*Volume of average annual flow (in million cubic metres)*
Indus	Near Manasarovar Lake (32°N,81°E) at 5180 m. elevation	2880 (709 in India)	1,178,440 (321,290 in India)	1,10,450 at Kalabagh in Pakistan
Jhelum	Verinag at 4900 m. altitude	724	34,775 upto Indo-Pak. boarder	27,890 at Mangia
Chenab	Bara Lacha Pass	1,180	26,155 upto Indo-Pak. Border	29,000 at Marala
Ravi India)	Near Rohtang Pass 8,000 at Madhopur		725	14,442 (5957 in
Beas	Near Rohtang Pass at 4,062m. height	460	20,303	15,800 at Mandi
Satluj	Manasarovar Rakas Lakes at 4,570 m. altitude	1450 (1050 in India)	25,900	16,600 at Rupnagar

After entering the plain at Rupnagar (Ropar), it turns westwards and is joined by the Beas at Harike. From near Ferozepur to Fazilka it forms its boundary between India and Pakistan for nearly 120 km.

During its onward journey it receives the collective drainage of the Ravi, Chenab and Jhelum rivers and about 70 km. further downstream, it joins the Indus a few kilometres above Mithankot. Out of its total length of 1450 km. it flows for 1050 km. in Indian territory. It drains an area of 25,900 sq. kms. and its average annual flow at Rupnagar (Ropar) is 16,660 million cubic metres.

The water assets of the Indus river system are shared by India and Pakistan according to the Indus Water Treaty signed between the two countries on 19th September, 1960. According to this treaty, India can utilize only 20 per cent of its total discharge of water.

THE GANGA RIVER SYSTEM

The Ganga river system consists of the master river Ganga and a large number of its tributaries. This system drains a very large area comprising the middle part of the Himalayas in the north, the northern part of the Indian Plateau in the south and the Ganga Plain in-between. The total area of the Ganga basin in India is 861,404 sq. km. which accounts for 26.3 per cent of the geographical area of the country. This basin is shared by seven states. These states are Uttar Pradesh (34.2%), Madhya Pradesh (23.1%), Bihar (16.7%), Rajasthan (13.0%), West Bengal (8.3%), Haryana (4.0%) and Himachal Pradesh (0.5%). The Union Territory of Delhi accounts for 0.2% of the total area of the Ganga Basin. Some tributaries like the Ghagra, the Gandak and the Kosi drain 190,000 sq. km. in Nepal. The Mahananda has 9,000 sq. km. catchment area in Bangladesh. Thus the total drainage basin of the Ganga is 1.06 million sq. kms.

The *Ganga* originates as Bhagirathi from the Gangotri glacier in Uttar Kashi District at an elevation of 7010 m. above sea level. It is joined by the Alaknanda at Devaprayag. But before Devaprayag it reached, the Pindar, the Mandakini, the Dhauliganga and the Bishenganga rivers pour into the Alaknanda and the Bheling flows into the Bhagirathi. The combined water of the Bhagirathi and the Alaknanda flows in the name of the Ganga below Devaprayag. After travelling 280km. from its source, the Ganga reaches Haridwar, debouches from the hills and enters plain area. From here it flows in south and south-east direction for a distance of 770 kms. to reach Allahabad. Here it is joined by the Yamuna which is its most important tributary. It sweeps another 300 km. eastwards to reach the Bihar plain. Near Rajmahal Hills it turns to the south-east and south of Farraka, it ceases to be known as the Ganga. It bifurcates itself into Bhagirathi-Hugli in West Bengal and Padma-Meghna in Bangladesh. After traversing 220 km. further down in Bangladesh, the Brahmaputra (or the Jamuna as it is known here) joins it at Goalundo and after meeting Meghna 100 km. downstream the Ganga joins the Bay of Bengal.

Before entering the Bay of Bengal, the Ganga, along with Brahmputra, forms the largest delta of the world between two arms the Bhagirathi/Hugli and the Padma/Meghna covering an area of 58,752 sq.-kms. The delta front of the Ganga is a highly indented area of about 400 km. length extending from the mouth of the Hugli to the mouth of the Meghna. The delta is made of a web of distributaries and islands and is covered by dense forests called the Sunderbans. A major part of the delta is a low-lying swamp which is flooded by marine water during high tide.

The total length of the Ganga river from its source to its mouth (measured along the Hugli) is 2525 kms. of which 1450 km. is in Uttar Pradesh, 445 km. in Bihar and 520 km. in West Bengal. The remaining 110 km. stretch of the Ganga forms the boundary between Uttar Pradesh and Bihar. The river flows majestically from Gangotri to Bay of Bengal with an average gradient of 9.5 cm. per km.

The Ganga is joined by a large number of tributaries both from the left as well as from the right. Majority of them originate in the Himalayan ranges but some of them have their sources in the Peninsular piateau.

The *Yamuna* is the largest and the most important tributary of the Ganga. It originates from the Yamnotri glacier on the Bandarpunch Peak in Garhwal at an elevation of 6,330.m., a source which is very close to that of the Ganga itself. After cutting across the Nag Tibha, the Mussoorie and the Shiwalik ranges it emerges out of the hilly area and enters plains near Tajewala. Many small streams such as the Rishiganga, the Uma and the Hanuman Ganga join it in the mountains. Its main affluent in the upper reaches is the Tons which also rises from the Bandarpunch glaciers at an altitude of 3900 m. and joins Yamuna below Kaisi before the latter leaves the hills. At this site, the water carried by the Tons is twice the water carried by the Yamuna. After completing a journey of about 300 km. in the plain area, it is joined by the 256 km. long Hindon in Uttar Pradesh. The Yamuna takes a southerly course upto Mathura and south- easterly in its onward journey upto Allahabad where it unites with the Ganga. Between Agra and Allahabad, the Yamuna receives some important tributaries originating from the Peninsular Plateau. These are the Chambal, the Sind, the Betwa and the Ken. The total length of the Yamuna from its origin to its confluence with the Ganga at Allahabad is 1376 km. and the drainage area is 366,223 sq. km. of which 139,468 sq. km. is that of the Chambal alone.

The *Chambal* rises 15 km. south-west of Mhow in the highlands of Janapao Hills (700 m.) in the Vindhya Range in Madhya Pradesh and takes a north-westerly course through the Malwa Plateau. It then enters a gorge at Chaurasigarh, 312 km. from its source. The gorge is 96 km. long and stretches upto Kota city. Below Kota, it turns to north-east and after reaching Pinahat, it turns to the east and runs nearly parallel to the Yamuna before joining it in the Etawah district of Uttar Pradesh. The river flows much below its banks due to severe erosion because of poor rainfall and numerous deep ravines have been formed in the Chambal Valley, giving rise to *badland topography*. The total length of the river is 1050 km. The Banas is an important tributary of the Chambal. It originates in the southern part of the Aravali Range, and takes a north-eastern course to join the Chambal near Sawai Madhopur. The Sind originates in Vidisha Plateau of Madhya Pradesh at an elevation of 543 m. It flows for a distance of 415 km. before it joins the Yamuna. It drains an area of 25,085 sq. km. *The Betwa* rises at an elevation of 470 m. in Bhopal district and joins the Yamuna near Hamirpur. It has a total length of 590 km. and a catchment area of 45,580 sq. kms. The *Dhasan* is its important tributary. The 360 km. long *Ken river* rising from the Barner Range of Madhya pradesh is another tributary which joins the Yamuna near Chila, some 60 km. downstream from the mouth of the Betwa.

The Son river springs from the Amarkantak Plateau, not far from the origin of the Narmada, at an elevation of about

600 m. After flowing for some distance to the north, it meets the Kaimur Range which turns its course to the north-east. It passes over the cascades in the hill reaches and further beyond through the Palamau district of Bihar. It joins the Ganga about 16 km. upstream of Danapur in Patna district after flowing for a distance of 784 km. from its source. It has a total catchment area of 71,259 sq. km. in which there are wide fluctuations of water flow changing with the change of season. The important tributaries of the Son are the *Johilla*, the *Gopat*, the *Rihand*, the Kanhar and the North *Koel*. Almost all the tributaries join it on its right bank.

The Damodar river rises in the hills of the Chota Nagpur plateau and flows through a rift valley. It used to cause devastating flood as a result of which it earned a dubious name of '*Sorrow of Bengal*'. After flowing through Bankura and Burdwan districts, it joins the Hugli 48 km. below Calcutta. The total length of the river is 541 km. and its catchment area is 25,820 sq. km.

Still more important tributaries of the Ganga originate in the Himalayas and join it on its left bank. The major tributaries of this category apart from the Yamuna are the Ramganga, the Gomti, the Ghagra, the Gandak the Burhi Gandak, the Bagmati, and the Kosi.

The *Ramganga* river rises in the Garhwal district of Uttar Pradesh at an altitude of 3,110 m. and enters the Ganga Plain near Kalagarh. It joins the Ganga at Kannauj after traversing a distance of 596 km. The Khoh, the Gangan, the Aril, the Kosi, and the Deoha (Gorra) are important tributaries which join the Ramganga. Its basin area covers 32,493 sq. km.

The *Ghaghra* river originates near the Guria Mandhata peak, south of Manasarovar in Tibet. Obviously it is a river of the trans-Himalayan origin and carries sufficient water. It is known as the Karnaili in Western Nepal. It first flows south-east and then south-southwest cutting across the Great Himalaya through a succession of steep defiles. Its important tributaries are the Sarda, the Sarju on the Bank of which Ayodhya is located and the Rapti. The Ghaghara joins the Ganga a few kilometres downstream of Chapra in Bihar after a 1080 km. long journey from its source. The total catchment area of the river is 127,950 sq. km. out of which 45% is in India and the rest lies in Nepal and Tibet. The river has a high flood frequency and has shifted its course seveal times. Its average annual flow is 94,400 million cubic metre.

The *Kali* river also rises in the high glaciers of snow covered region of the trans-Himalaya. It has several feeders in the high ranges and forms the boundary between Nepal and Kumaon for most of its transit across the mountains. It is known as the *Sarda* or *Chauka* after it reaches the plain near Tanakpur. Below this point it takes a south-easterly course and joins the Ghaghara at the tri-junction of Sitapur-Barabanki-Bahraich districts

The *Gandak* which originates near the Tibet- Nepal border at a height of 7620 m. receives a large number of tributaries in Nepal Himalaya, the most outstanding being the *Kali Gandak*, the *Mayangadi*, the *Bari* and the *Trishuli*. It debouches into the plains at Tribeni and pours into the Ganga at Hajipur in Vaishali district of Bihar after flowing for a distance of 425 km. in India. Its drainage area is 46,300 sq. km. out of which 7,620 sq. kms. is in India. The average annual flow is 52,200 million cubic metres.

The *Burhi Gandak* originates from the western slopes of Sumesar hills near the India-Nepal border and flows in south-east direction. It joins the Ganga opposite Monghyr town. Its length is 610 km. and its drainage area is 12,200 sq. km.

The *Kosi* is formed by the confluence of three rivers, the *Sun Kosi, the Arun Kosi* and the *Tamur Kosi*, which originate in the snow covered peaks of Sikkim, Nepal and Tibet. They are fed by the glaciers of the Gauri Shankar—Everst—Makalu—Kanchanjunga group of peaks. These three streams contribute respectively 44%, 37% and 19% of the total water flow in the river. They unite north of the Mahabharata Range to form the Kosi. The river enters the Tarai of Nepal after cutting a narrow gorge for 10 km. in the Mahabharata Range at Chatra. The Kosi flows for a distance of 730 km. in India and joins the Ganga near Kursela. The total drainage area of the river is 86,900 sq. km. out of which 21,500 sq km. lies in India, Soon after debouching into the plain the river becomes sluggish and large scale deposition of eroded material takes place. The river channel is braided and it shifts its course frequently.

It has been estimated that the Kosi has shifted its course westwards by 112 km. during the last 250 years. This has result in frequent devastating of floods and has converted about 9,000 sq. km. cultivable land into waste land in northern Bihar. Thus, the river is often termed as the 'Sorrow of Bihar'. In order to tame this river, a barrage was constructed in 1965 near Hanuman Nagar in Nepal. Embankments for flood control have been constructed as a joint venture of India and Nepal.

Table 8.2 : The Ganga Drainage System

Name of the river	*Source*	*Length (in km.)*	*Area drained (sq. km.)*	*Volume of average annual flow (in million cubic metres)*
Ganga	Gangotri Glacier at 7010 m.	2,525	861,404	1,52,000 at Allahabad, 4,59,040 at Patna
Yamuna	Yamnotri Glacier at 6330 m.	1,376	366,223	93,020 at Allahabad
Chambal	Near Mhow	1,050	139,468 confluence with	30,050 at
the Yamuna				
Ramganga	Garhwal district at 3110m.	596	32,493	15,258
Ghaghara	Near Guria Mandhota peak south of Manasarovar	1,080	127,950	94,400
Gandak	Tibet-Nepal border at 7620 m.	425 in India	46,300 (7620 in India)	52,200
Kosi	Sikkim-Nepal Tibet Himalaya	730 in India	86,900 (21,500 in India)	61,500

THE BRAHMAPUTRA RIVER SYSTEM

The Brahmaputra (meaning the *son of Brahma*) rises in the great glacier in the Kailas range of the Himalayas a little south of the Lake Konggyu Tsho at an elevation of about 5150 m. located at 30° 31' N latitude and 82° 10' E longitude. This source is about 150 km. away from the source of the Indus and only 35 km. from the birth place of the Satluj. Both these rivers flow westwards while the Brahmaputra flows eastwards from this region. *Mariam La* pass separates the source of the Brahmaputra from the Manasarovar Lake. With a total length of 2,900 kms. the Brahmaputra is one of the longest rivers of the world and passes through Tibet, India and Bangladesh.

Known as the *Tsangpo* (meaning 'The Purifier'), in Tibet and *Yarlung Zangbo Jiangin* in Chinese language, the Brahmaputra flows eastwards in Southern Tibet for about 1800 kms. and for most part of this journey it passes through the depression formed by the *Indus- Tsangpo Structure Zone* between the great Himalayas in the south and the Kailas Range in the north. Inspite of the exceptionally high altitude of the land through which the Tsangpo flows, it has a gentle slope and the river is sluggish and has a wide navigable channel for about 640 km. from Lhatse Dzong down-stream. This is one of the most remarkable navigable waterways of the world where boats sail at an altitude of 3,000 metres and above. Its bed is 3,525 m. high at Tradom (Teladuomu) and 3,300 m. at Shigatse. It receives a large number of tributaries in Tibet. The first major tributary is the Raga Zangbo from the north meeting the Tsangpo near Lhatse Dzong. The river Ngangchu flows through the trade centre of Gyantse in the south and joins the main river near Zhikatse. Further east, the Kyichu (Gya Chhu) from the north runs past the sacred town of Lhasa and joins it near Chushul Dz. At Tsela Dz, the river is joined by the Griamda from the north.

Towards the end of its journey in Tibet, it abruptly turns to north-east and north and then traverses in a succession of rapids between high mountains of Gyala Peri (7151 m.) and Nancha Barwa (7756 m.). Further it turns to the south and south-west and cuts across the eastern Himalaya through the Dihang or Siang Gorge and emerges from the mountains near

Sadiya in the Assam Valley. Here it first flows under the name of Siong and then as the Dihang. The Dihang gorge is only 50 metres wide at places but is 5485 m. below Namcha Barwa. The steepness of its slope can be judged from the fact that its altitude falls suddenly from 2450 m. north of Namcha Barwa to only 135 m. at Sadiya. Here it is joined by two important tributories viz. the Dibang (or Sikang) from the north and Lohit from the south forming what looks like a '*delta in reverse*'.

From Sadiya onwards, this mighty river is known as the Brahmaputra and flows majestically in the Assam Valley for a distance of about 72 km. Here also, a large number of tributaries, both from the north and from the south, pay their tribute to the master river. The main streams merging with the Brahmaputra from the north are, Subansiri, Kameng, Belsiri, Dhansiri (north), NyeraAma, Manas—Mora—Manas, Champaman, Gangadhar, Raidah, Dharia and Tista. The Tista was a tributary of the Ganga prior to the devastating floods of 1787 after which it diverted its course eastwards to join the Brahmaputra. Those pouring in the main river from the south are the Dibru, Burhi Dihing, Noa Dihing, Dikhu, Dhansari (south) and Kalang.

The Brahmaputra has a braided channel for most of its passage through Assam. There is a constant shifting of the river channels and the sandy shoals. Its southward shift in the Assam plains has been quite conspicuous in the recent years. In this process it has completely swallowed the town of Palasbari in Kamrup district and is now in the process of nijbbling away Dibrugarh and Goalpara towns. It carries a lot of silt and there is excessive meandering. The river is nearly 16 km. wide at Dibrugarh and forms many islands, the most important of which is *Majuli*. It is 90 km. long and measures 20 km. at its widest, having an area of 1250 sq. km. With rainfall concentrated during the monsoon months only the river has to carry enormous quantities of water and silt which results in disastrous floods in the rainy season. The floods caused by the Brahmaputra in Assam Valley affect on an average area of 8 to 10 lakh sq. km. The Brahmaputra is thus truly a River of Sorrow. However, the river is navigable for a distance of 1384 km. upto Dibrugarh and serves as an excellent inland water transport route.

Traversing round the stairs of the Garo Hills, the Brahmaputra bends southwards and enters Bangladesh near Dhubri. It flows for a distance of 270 km. in the name of Jamuna river and joins the Ganga at Goalundo. The united stream of the Jamuna and the Ganga flows further in the name of Padma. About 105 kms. further downstream, the Padma is joined on the left bank by the Meghna, originating in the mountainous" region of Assam. From the confluence of Padma and Meghna, the combined river is known as the Meghna which makes a very broad estuary before pouring into the Bay of Bengal. The total drainage area of the Brahmaputra system is 580,000 sq. km. out of which 240,000 sq. km. is in India.

THE PENINSULAR RIVER SYSTEMS

Almost all the major rivers of the Peninsular India are in their mature stage and have reached the base levels of their erosion. They flow in comparatively shallow and almost graded valleys. The velocity of water in the rivers and the load carrying capacity of the streams is low due to low gradient and the rivers form big deltas at their mouths. This is especially observed in the east flowing rivers pouring into the Bay of Bengal. But the west flowing rivers of Narmada and Tapi as well as those originating from the Western Ghats and falling in the Arabian sea form estuaries in place of deltas. Although the general direction of flow of the Peninsular rivers is from west to east, a careful study reveals at least three main directions of flow:

(i) The Mahanadi, the Godavari, the Krishna, the Cauvery and several smaller rivers draining south-east into the Bay of Bengal.

(ii) The Narmada and the Tapi flowing west as well as several small streams originating from the western Ghats flow westwards into the Arabian Sea.

(iii) Tributaries of the Ganga and the Yamuna such as the Chambal, the Betwa, the Ken, the Son and the Damodar flow in the north-easterly direction.

THE EAST FLOWING RIVERS OF THE PENINSULA

The Mahanadi (literally meaning big river) is an important river of the Peninsular India. It has its source in the northern foothills of Dandakaranya near Sihawa in Raipur District of Madhya Pradesh at an elevation of 442 m. Its Supper course lies in the saucer-shaped basin called the 'Chhattisgarh Plains'. This basin is surrounded by hills on the north, west and south as a result of which a large number of tributaries join the main river from these sides. The main tributaries are the Ib (251 km), the Mand (241 km.), the Hasdo (333 km.) and the Sheonath (393 km.) on the left bank and the Ong (204 km.), the Jonk (196 km.), and the Tel (295 km.) on the right bank. From its source, the river takes a north easterly course. Beyond Seorinarayan it flows eastwards and after entering Orissa, it turns southwards below the Hirakud Dam. Further below it turns eastwards near Sonepur. On reaching Eastern Ghats, the river flows through a narrow Gorge for 23 km. near Tikkarpara Range and finally emerges in a delta at Naraj 11 km. west of Cuttack. The Mahanadi finally empties itself in the Bay of Bengal after flowing for a distance of 857 km. The delta of Mahanadi spreads over an area of 9,500 sq. km. and is over 150, km. broad. The river drains a total area of 141,600 sq. km. of which 53.1 per cent is in Madhya Pradesh and 46.5 per cent in Orissa, the rest being in Bihar and Maharashtra. The river carries on an average about 67,000 million cubic metres of water annually.

The *Godavari* is the largest river system of the Peninsular India and is next only to the Ganga and the Indus Systems regarding sanctity picturesqueness and utility and is held in reverence as *Vridha Ganga* or *Dakshina Ganga*. Its total length is 1465. It has a catchment area of 312, 812 sq. km. of which 48.6 per cent is in Maharashtra, 23.8 per cent in Andhra Pradesh, 20.7 per cent in Madhya Pradesh, 5.5 per cent in Orissa and only 1.4 per cent in Karnataka. The source of this river is in the Trimbak Plateau of North Sahyadri near Nasik in Maharashtra which is only 80 km. from the shore of the Arabian Sea. From its source it flows eastwards in a narrow rocky bed upto Nasik but the river valley opens out below this point. It receives a large number of tributaries both from the left as well as from the right. But the left bank tributaries are more numerous in number and larger in size than the right bank tributaries. The Manjra (724 km.) is the only important right bank tributary. It originates from Jamkhed Hill in Central

Maharashtra and joins the Godavari near Kondalwadi after passing through the Nizam Sagar. The Penganga, the Wardha, the Wainganga, the Indravati and the Sabari are important left bank tributaries. The Penganga (676 km.) rises from the Buldana Range and joins the Wardha River (483 km.) near Ghughus. The Wardha in its turn joins the Wainganga. The united Wardha and Wainganga rivers become the short span *Pranhita* river which joins the Godawari below Sironcha. The *Indravati* river from the Kondhan Hills of Eastern Ghats joins the master river about 48 km. downstream from Sironcha. Below its confluence with Indravati, the Godavari flows in a gorge, 60 km. long and 200 m. wide through Eastern Ghats. It is located about 100 km. from the mouth of the river and is supposed to be formed due to faulting. Below Rajahmundry. the river divides itself into two main streams, the *Gautami Godavari* on the east and the *Vashishta Godavari* on the west and forms a large delta before it pours into the Bay of Bengal. The current at Rajahmundry is not rapid and varies from 1.2 to 3.3 metres per second. The delta has a front of 120 km. and projects about 35 km. into the sea. The Godavari causes heavy floods in its lower course below Polawaram. The Godavari is navigable upto a distance of 300 km. from its mouth.

The Krishna is the second largest east flowing river of the Peninsula. It rises in the Western Ghats just to the north of Mahabaleshwar, about 64 km. from the Arabian Sea and flows for a distance of 1400 km. to the Bay of Bengal in a general easterly direction. Its total drainage area is 258,948 sq. km. of which 43.8 per cent lies in Karnataka, 29.4 per cent in Andhra Pradesh and 26.8 per cent in Maharashtra. The total annual discharge of the Krishna basin is 67,670 million cubic metres. The Koyna, the *Ghataprabha*, the *Malprabha*, the *Bhima*, the *Tungabhadra*, the *Musi* and the *Muneru* are its important tributaries. The *Koyna* is a small tributary but is very famous for Kyna Dam. The *Bhima* originates from the Matheron Hills and joins the Krishna 26 kms. from Raichur after flowing in the south-easterly direction for a distance of 861 km. Mula, Mutha Ghod and Nora are its sub-tributaries. The Tungabhadra is formed by the unification of the Tunga and the Bhadra originating from Gangamula in the Central Sahyadri. Its total length is 531 km. At Wazirabad, it receives its last important tributary, the Mui, on whose banks the famous city of Hyderabad is located. The Krishna forms a large delta spreading over an area of 4,600 sq. km. with a shoreline of about 120 kms. The Krishna delta appears to merge with that formed by the Godavari and extends about 35 km. into the sea.

The Cauvery is the most revered and secred river of south India and is designated as the 'Dakshina Ganga' or 'the Ganga of the South'. The Source of this river lies at Talakaveri on the Brahmagiri range of hills in the Western Ghats at 1,341 m. elevation (12° 25' N and 75° 34' E) situated in the Coorg Plateau (Kadagu district of Karnataka. It flows eastwards for a distance of about 800 km. before it empties in the Bay of Bengal. Its total drainage area is 87,900 sq. km. of which Tamil Nadu has 55.5%, Karnataka 41.2% and Kerala 3.3%. This river is unique in the sense that its upper catchment area receives rainfall during summer by the south-west monsoon and the lower catchment area during winter season by the retreating north-east monsoon. It is therefore, almost a perennial river with comparatively less fluctuations in flow and is very useful for irrigation and hydroelectric power production. Thus the Cauvery is one of the best regulated rivers and 90 to 95 per cent of its irrigation and power production potential is already harnessed.

The Cauvery river falls rapidly by 450 m. from its source of origin within a short distance of 8 km. The middle course of the river over the 750 m. high Mysore Plateau is characterised by broad and sweeping meanders. The river discends from the South Karnataka Plateau to the Tamil Nadu Plains through the Sivasamudram waterfalls (101 m. high). The river which was more than one kilometre wide above the Sivasamudram Falls, narrows down considerably below it and enters a long, picturesque gorge, 200 m. deep at places, cut through in Eastern Ghats. The river divides itself into two distinct channels at Srirangam. The northern channel is called Kollidam (Coleroon) while the southern one retains the name Cauvery. The delta formation starts from a point about 16 km. away from Tiruchirappalli. The Cauvery has formed a quadrilateral delta spreading over an area of 8,000 sq. kms. It has almost straight front which runs for a distance of 130 km. along the coast of Bay of Bengal.

The water flowing in the Cauvery is supplemented by a large number of tributaries which join the master river at different places. The main tributaries are the *Herangi* the *Hemavati, Lokpavani, Srimsha* and *Arkavati* from the north and *Laksmantirtha, Kabani, Suvarnavati, Bhavani* and *Amravati* from the south.

Among the other east flowing rivers of the Peninsular India are, from north to south, the Subarnarekha, the Brahmani, the Penneru, the Ponnaiyar and the Vaigai. The *Subarnarekha* originates from he Ranchi Plateau in Bihar at an elevation of 600 m. and flows in south-east direction forming the boundary between West Bengal and Orissa in its lower course. It joins Bay of Bengal forming an estuary between the Ganga and Mahanadi deltas. Its total length is 395 km. and its catchment area of 19,300 sq. km. is shared by Bihar (71%), Orissa (11%) and West Bengal (18%). The Brahmani river comes into existence by the confluence of the Koel and the Sankh rivers near Rourkela. It has a total length of 800 km. and a catchment area of 39,033 sq. kms. About 40 per cent of its catchment area is in Bihar and the rest is in Orissa and Madhya Pradesh. Its main tributaries are the Kura, the Sankhad and the Tikra. Its mouth becomes the northern end of the Mahanadi delta. The Penneru river springs from the Nandi Durg peak in Karnataka and flows in northward direction. It then enters Andhra Pradesh and takes an easterly course. It forms a narrow estuary before it joins the Bay of Bengal. The total length of the river is 597 km. Its drainage area of 55,213 sq. km. is shared by Andhra (88%) and Karnataka (12%). The principal tributaries of this river are the *Jayamangali the Kunderu, Saigileru, Chitravari, Papagni* and *Cheyyeru*. The Ponnaiyar is a small stream which is confined to the coastal area only. South of the Cauvery delta, there are several streams, of which the Vaigai is the longest. This flows through dry channels and tends to get lost intermittently and appear again on the surface.

THE WEST FLOWING RIVERS OF THE PENINSULA

The west flowing rivers of the Peninsular India are fewer and smaller as compared to their east flowing counterparts. The two major west flowing rivers are the Narmada and the

Tapi. This exceptional behaviour of these two rivers is explained by the supposition that they do not flow in the valleys formed by themselves but have usurped for their channels two fault planes running parallel to the Vindhyas. These faults are supposed to have originated with the bending or *'sagging'* of the northern part of the Peninsula at the time of upheaval of the Himalayas. It is interesting to note that the Peninsular rivers which fall into the Arabian Sea do not form deltas, but only estuaries. This is due to the fact that the west flowing rivers, especially the Narmada and the Tapi flow through hard rocks and are not able to form distributaries before they enter the sea. The Sabarmati, Mahi and Luni are other rivers of the Peninsular India which flow westwards. Hundreds of small streams originating in the Western Ghats flow swiftly westwards and join the Arabian Sea.

The Narmada is the largest of all the west flowing rivers of the Peninsular India. It rises from Amarkantak in Madhya Pradesh and flows westwards through a rift valley between the Vindhyan Range on the north and the Satpura range on the south. Its total length from its source in Amarkantak and its estuary in the Gulf of Khambhat is 1,310 km. For 1,078 km. it flows through Madhya Pradesh. For the next 32 km. it forms the boundary between Madhya Pradesh and Maharashtra and for another 40 km. between Maharashtra and Gujarat. The remaining 160 km. of its course is in Gujarat. The total drainage area of the river is 98,796 sq. km. which is shared by Madhya Pradesh (87%), Gujarat (11.5%) and Maharashtra (1.5%). After flowing for 400 km. from the source, the river slopes down Jabalpur, where it cascades 15m. into a gorge to form the most spectacular and world famous Dhuan Dhar (Cloud of Mist) Falls. Since the gorge is composed of marble, it is popularly known as the Marble Rocks. The average discent of the river in its upper basin is 7-9 metres per km. Below Jabalpur, it flows in a narrow elongated and well defined basin and forms a few rapids. It makes two waterfalls of 12 m. each at Mandhar and Dardi. Near Maheshwar the river again descends from another small fall of 8 m, known as the Sahasradhara Falls. Emerging from the hills near Gardeshwar, it meanders through an alluvial plain past Broach and makes an estuary before entering the Gulf of Khambhat. There are several islands in the estuary of the Narmada of which Aliabet is the largest. At its confluence with the sea, the mouth of the river is about 28 km. wide. The Narmada is navigable upto 112 km. from its mouth.

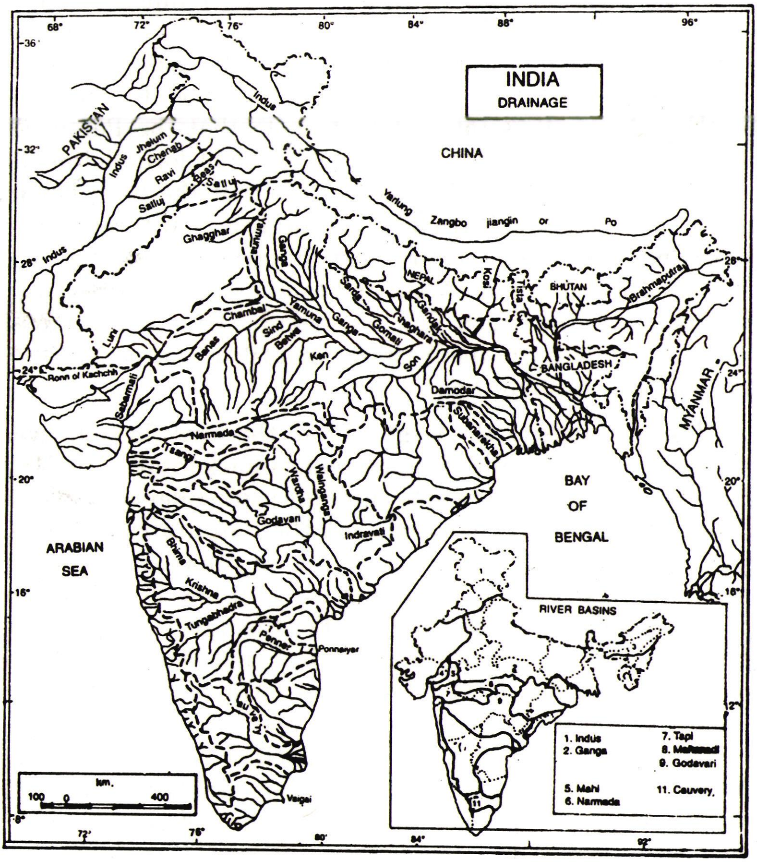

INDIA
DRAINAGE
68°
72°
76°
80°
84°
88°
96°
36°
32°
28°
24°
20°
16°
12°
8°
PAKISTAN
CHINA
Indus
Jhelum
Chenab
Ravi
Beas
Satluj
Ghagghar
Yamuna
Ganga
Yarlung
Zangbo
jiangin
or
Po
NEPAL
Kosi
Tista
BHUTAN
Brahmaputra
Sarda
Gomati
Ghaghara
Gandak
Chambal
Sind
Betwa
Ken
Son
Luni
Banas
Sabarmati
Ronn of Kachchh
BANGLADESH
MYANMAR
Damodar
Subarnarekha
Narmada
Tapi
Wardha
Wainganga
Godavari
Indravati
BAY
OF
BENGAL
ARABIAN
SEA
Bhima
Krishna
Tungabhadra
Penner
Ponnaiyar
Kaveri
Vaigai
km.
100
0
400
RIVER BASINS
1. Indus
2. Ganga
5. Mahi
6. Narmada
7. Tapi
8. Mahanadi
9. Godavari
11. Cauvery.
92°

Fig. 8.4 : India—Drainage.

Since the river flows through a narrow valley confined by precipitous hills, it does not have many tributaries. The absence of tributaries is especially noted on the right bank of the river where the Hiran is the only exception. It is 188 km. long and flows parallel to the Bhanru Range in Jabalpur district before falling into the Narmada, north-east of Chhindwara. The other right bank tributaries are the Orsang, the Barna and the Kolar. A few left bank tributaries drain the northern slopes of the

Satpura Range and join the Narmada at different places. The important tributaries joining the Narmada on its left bank are the Burhner (m., km.), the Banjar (184 km.), the Shar (129 km.), the Shakkar (161 km.) the Tawa (172 km) and the Kundi (169 km.)

The Tapi (also known as the Tapti) is the second largest west flowing river of the Peninsular India and is known as 'the twin' or 'the handmaid' of the Narmada. It originates from the sacred tank of Multai on the Satpura Plateau in Betui district of Madhya Pradesh at an elevation of 730 m. above sea level. It first traverses on open plain and (hen plunges into a rocky gorge of the Satpura hills between the Kalibhit Range in Nimar and Chikalda in Berar. At a distance of 192 km. from its source,. the river enters the Nimar region. After crossing the Nimar region of Madhya Pradesh it enters the Khandesh Plain of Maharashtra, lying between the Satpura and the Ajanta Ranges. On entering the Khandesh Plain, it receives the Puma river on the left bank. This is the main tributary of the Tapi which originates in the Gawilgarh Hills and joins the main river near Bhusawal. Further west it crosses the Western Ghats through a deep and a narrow valley, passes through the alluvial plain of Surat and makes an estuary of before falling into Gulf of Khambhat.

The total length of the river is 730 km. About 48 km. stretch of its course is tidal and the river is navigable for only about 32 km. from the sea. The total catchment area of the river is 65,145 sq. km. of which 15 per cent is in Madhya Pradesh, 79 per cent in Maharashtra and 6 per cent in Gujarat. The important tributaries of this river apart from the Purna River, are the Betui, Patki, Ganjal, Dathranj, Bokad, Bokar Suki, More, Kanki, Guli, Aner, Arunavati, Gomai and Valer on right bank and Ambhora, Khursi, Khandu, Kapra, Sipra, Garja, Khokri, Utaoli, Mona, Vaghur, Girna, Bori, Panjhara, Buray and Amravati on the left bank.

The Sabarmati is the name given to the combined streams the Sabar and Hathmati. It rises from the hills of Mewar in the Aravali Range and is 320 km. long. Its total drainage area is 21,674 sq. km. which is shared by Rajasthan (19%) and Gujarat (81%). It flows through a gorge at Dharoi and falls into the Gulf of Khambhat. The important tributaries of this river are the Hathmati, the Sedhi, the Wakul, the *Harnav*, the *Meshwa* and the Vatrak. The average annual flow of this river is 3,200 million cubic metre.

Table 8.3 : Major Rivers of the Peninsular India

Name of the river	*Source*	*Length in km.*	*Areas rained (sq. km.)*	*Volume of average annual flow (million cubic metres)*	*Important tributaries*
Mahanadi	Dandakaranya near Sihawa in Raipur district of M. P.	857	141,600	67,000	Ib, Mand, Hasdo, Sheonath, Ong, Jonk, Tel
Godavari	Trimbak Plateau near Nasik in Maharashtra	1,465	312,812	105,000	Manjra, Penganga, Wardha, Wainganga, Indravati, Sabari, Pranhita
Krishna	Near Mahabaleshwar	1,400	258,948	67,670	Koyna, Ghatprabha, Malprabha, Bhima, Tungabhadra, Musi, Muneru
Cauvery	Talkaveri in Western Ghats	800	87,900	20,950	Herangi, Hemavati, Lokpavani, Shimsha, Arkavati, Lakshmanatirtha, Kabani, Suvanavati, Bhavani, Amaravati
Nannada	Amarkantak Platean	1,310	98,796	40,700	Hiran, Orsang, Bama, Kolar, Burhner, Banjar, Shar, Shakhar, Tawa, Kundi
Tapi	Multai in Betul Distt. of M.P.	730	65,145	17,980	Puma, Betul, Patki, Ganjal, Dathranj, Bokad, Amravati

The Mahi river rises in the Vindhyas at an elevation of 500 m. and empties itself into the Gulf of Khambhat after flowing for a distance of 533 km. It drains an area of 34,862 sq. kms. which is shared by Madhya Pradesh (19%), Rajasthan (47%) and Gujarat (34%). The main tributaries of this river are the

Som, the Anas and the Panam. The Luni or the Salt River (Lonari or Lavanavari in Sanskrit) is named so because its water is brackist below Balotra. Its source lies in the west of Ajmer in the Aravalli at an elevation of 550 m. and it flows in a south-west direction. It is a small stream but has got the distinction of flowing through in the Thar Desert. The river is known as the *Sagarmati* in its upper course. It is joined by the Sarsuti tributary after passing Govindgarh and it is from this confluence that the river gets its proper name as the Luni. It traverses for a distance of 482 km. and is finally lost in the marshy grounds at the head of the Rann of Kuchchh. The river has a low gradient and flows through a wide plain without a well marked valley.

West Flowing Rivers of the Sahyadris

About six hundred small streams originate from the Western Ghats and flow westwards to fall into the Arabian Sea. The western slopes of the Western Ghats receive heavy rainfall by the south-west monsoons and are able to feed such a large number of streams. Although, only about 3% of the areal extent of the basins of India is drained by these rivers, they contain about 18% of the country's water resources. The important rivers falling in this category are the Mandovi, Zuari and Rachol in Goa; Kalinadi, Gangavalli-Bedti, Sharvati, Tadri and Netravati in Karnataka, and Beypore, Pannam, Bharatapuzha, Periyar and

Pamba in Kerala. Most of the streams flow swiftly down the steep slope and some of them make waterfalls. The famous Jog or *Gersoppa Falls* (289 m.) made by the Saravati river is the highest in India.

INLAND DRAINAGE

Some rivers of India are not able to reach the sea and constitute inland drainage. Large parts of the Rajasthan desert and parts of Aksai Chin in Ladakh have inland drainage. The Ghaggar is the most important river of inland drainage. It is a seasonal stream which rises on the lower slopes of the Himalayas and forms boundary between Haryana and Punjab. It gets lost in the dry sands of Rajasthan near Hanumangarh after traversing a distance of 465 km. Earlier, this river was an affluent of the Indus, the dry bed of the old channel is still traceable. Its main tributaries are the Tangei, the Markanda, the Saraswati and the Chaitanya. It contains a lot more water in rainy season when its bed becomes 10 km. wide. Most of the streams draining western slopes of the Aravalli Range dry up immediately after they enter the sandy arid areas to the west of this range.

DIFFERENCES BETWEEN THE HIMALAYAN AND THE PENINSULAR RIVER SYSTEMS

The Himalayan rivers are quite different from the rivers of the Peninsular India from the point of view of the drainage features and hydrological characteristics. A brief summary of these differences is given below :

Table 8.4

Basis	*The Himalayan River System*	*The Peninsular River System*
1. Name	These rivers originate from the lofty Himalayan ranges and are named as the Himalayan rivers.	These rivers originate in the Peninsular Plateau and are named as Peninsular rivers
2. Basins	These rivers have large basins and catchment areas. The total basin area of the Indus, the Ganga and the Brahmaputra is 11.78, 8.61 and 5.8 lakh square kilometres respectively.	These rivers have small basins and catchment areas. The Godavari has the largest basin area of 3.12 lakh square kilometres only which is less than one-third of the basin area of the Indus.
3. Valleys	The Himalayan rivers flow through deep I-shaped valleys called gorges. These gorges have been carved out by down cutting carried on side by side with the uplift of the Himalayas. These are examples of antecedent drainage.	The Peninsular rivers flow in comparatively shallow valleys. These are more or less completely graded valleys. The rivers have little erosional activities to perform. These are examples of *consequent drainage.*

4. Water flow	The Himalayan rivers are perennial in nature, *i.e.*, the water flows throughout the year in these rivers. These rivers receive water both from the monsoons and snowmelt. The perennial nature of these rivers make them useful for irrigation.	The Peninsular rivers receive water only from rainfall and water flows in these rivers in rainy season only. Therefore, these rivers are seasonal or non-perennial. As such these rivers are not much useful for irrigation.
5. Stage	These rivers flow across the young fold mountains and are still in a youthful stage.	These rivers have been flowing in one of the oldest plateaus of the world and have reached maturity.
6. Meanders	The upper reaches of the Himalayan rivers are highly tortuous. When they enter the plains, there is a sudden reduction in the speed of flow of water. Under these circumstances these rivers form meanders and often shift their beds.	The hard rock surface and non-alluvial character of the plateau permits little scope for the formation of meanders. As such, the rivers of the Peninsular Plateau follow more or less straight course.
7. Deltas and Estuaries	The Himalayan rivers form big deltas at their mouths. The Ganga-Brahmaputra delta is the largest in the world.	Some of the Peninsular rivers, such as the Narmada and the Tapi form estuaries. Other rivers such as the Mahanadi, the Godavari, the Krishna and the Cauvery from deltas. Several small streams originating from the Western Ghat? and flowing towards the west enter the Arabian Sea without forming any delta.

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Index

A

- Advectional inversion of temperature, 112
- African veld, 58
- Albedo, 83, 129
  - of different kinds of surfaces, 105
- Alpine Tundra climate, 71
- Arctic Tundra climate, 71
- Atmosphere, 68
  - absorption, 82
  - constituents of the atmosphere, 70-71
  - factors affecting the distribution of insolation, 77
    - angle of the sun rays, 77-79
    - distance between the earth and the sun, 80-81
    - effects of the atmosphere, 81-82
    - length of day, 79-80
    - sunspots, 81
  - heat budget of the earth and the atmosphere, 73, 83-84
    - definition, 7374
  - mechanism of solar radiation, 74-77
    - Stefan-Boltzmann law, 74
    - Wien displacement law, 74
  - reflection, 83
  - scattering, 82
  - Tundra climate, 71
    - location, 71-72
    - natural vegetation, 72-73
    - precipitation, 72
- Atmosphere structure, 88-132
  - accumulated temperature, 122
  - anomalous temperature, 125
  - attitude, 102
  - chemical composition of the atmosphere, 93-94
    - heterosphere, 94
    - homosphere, 93
  - conduction, 97-98
  - controls of weather and climate, 95-96
  - distance from the coast, 102
  - distribution of temperature, 101
    - factors controlling, 101
    - latitudes, 101-102
    - ocean currents, 101
  - elements of weather and climate, 95
  - heating and cooling of the atmosphere, 96-97
  - – of the atmosphere by direct insolation, 97
  - horizontal distribution of temperature, 116
    - isotherms, 117
    - July and January, 117-119

introduction, 88
    mesosphere, 92
    stratosphere, 89-92
    thermosphere, 92-93
    troposphere, 88-89
inversion of temperature, 108-109, 114-116, 131-132
isothermal layer, 132
mean temperatures, 100
nature of ground slope, 104-105
– – – surface, 105
– – land and water, 103-104
– – surface, 128-129
regional distribution of temperature, 119-121
    frigid zone, 120-121
    temperature zone, 119
    tropical zone, 119
relief, 130-131
sunshine, 122-124
    distribution of sunshine, 123
    instruments, 123-124
    measurement and recording, 122-123
    scale of temperature, 123
temperature factors, 125
    insolation, 125-128
terrestrial radiation, 98
    convention, 99
    Stefan-Boltzmann law, 98
    Wien displacement law, 98
thermals, 130
vertical distribution of temperature, 106-108
winds, 130
world temperature distribution, 121-122
    sensible temperature, 121
Australian downs, 59

B

Ballons-sondes, 68

C

Canopy Layer woodland Savanna, 44
Chinese aggression, 9
Climate, 26-87
    air pressure and winds, 36-37, 48
    China type of climate, 50
    – – – air pressure and winds, 53
    – – – precipitation, 53-55
    – – – temperature, 52-53
    classification by Thornthwaite, 28
        classification of 1931 , 29
        evaluation of Thornthwaite schemes, 29-30
        precipitation effectiveness, 28
    classification of G.T. Trewartha, 30-31
        boreal climate, 33
        dry climates, 31-32
        micro thermal climate, 33
        middle latitudes wet climates, 32-33
        polar climate, 33-34
        tropical humid climates, 31
    climatic factors and elements, 67-68
    climatology and meteorology, 64
        meteorology, 65-66
        weather and climate, 64-65
    general features of climates, 63
        climatic changes, 63-64
    introduction, 26-28
        monsoon, 26
        rainfall, 27
        summer, 26
    Koeppen classification, 35

- local climate and microclimatology, 66-67
- mediterranean climate, 45
- – location, 45-46
- – temperature, 46-48
- natural vegetation, 49-50
- precipitation, 37-39, 48-49
  - effects of climate on natural vegetation, 39-40
  - rainfall regime, 38
  - variability of rainfall, 38-39
- rainfall, 38, 42-43
- regional characteristics, 57-59
- Savanna air pressure and winds, 41-42
- – climate, 40
- – location, 40-41
- – temperature, 41
- Steppe climate, 55
- – location, 55-56
- – precipitation, 57
- – temperature, 56-57
- West European type of climate, 59
- – – – – location, 59
- – – – – natural vegetation, 62-63
- – – – – precipitation, 61-61
- – – – – temperature, 60-61

Climatic contrasts, 13

Coniferous forests, 255

D

Diffuse reflection, 83

Drainage, 294-326
- antecedent drainage, 299
- basin, 294
- Brahmaputra river system, 312-314
  - Tsangpo, 312
  - Yarlung Zangbo Jiangin, 312
- Burhi Gandak, 310
- difference between the himalayan and the peninsular river systems, 324-325
- drainage system of India, 297-298
  - minor river basins, 298
  - major river basins, 297
  - medium rivers basins, 297
- east flowing rivers of the peninsula, 314-318
  - Cauvery, 317
  - Krishna, 316
  - Mahanadi, 314
  - River Godavari, 315
- evolution of the Hmalayan rivers, 299-301
- Himalayan rivers, 298-299
- inland drainage, 323-324
- introduction, 294-297
- peninsular rivers, 296, 314
- river
  - Beas, 304
  - Brahmaputra, 312-314
  - Burhi Gandak, 310
  - Chambal, 308
  - Chenab, 303, 305
  - Damodar, 309
  - Gandak, 310
  - Ganga, 306-311
  - Ghaghra, 309
  - Godavari, 315
  - Indus, 302-306
  - Jhelum, 303, 305
  - Kali, 310
  - Kosi, 310
  - Krishna, 316

        Mahanadi, 314
        Mahi, 322
        Narmada, 318, 319
        Ramganga, 309
        Ravi, 304-305
        Sabarmati, 321
        Son, 308
        Tapi, 321
Droughts and floods, 282-293
    droughts, 282-286
    flood control programmes and policy, 290-291
    flood forecasting, 291-292
    floods, 286-290
    introduction, 282

E

Eastern boundaries, 9
Electromagnetic radiation, 75
Energy surplus area, 86
Exosphere, 93

F

Fog, 114
Forest policy, 270
Frontier, 8

G

Ganga drainage system, 311
Grass savanna, 44
Ground layer, 43
Ground surface inversion, 109

H

Hobbs, J. E., 87

I

India geographical unit, 6
Indian ocean, 19, 20
Insolation or solar radiation, 75, 76
Inter Tropical convergence, 41, 42, 43
Inversion of temperature, 115
Ionosphere, 92
Isotherms, 118, 119

K

Koeppen classification, 35
Koeppen scheme, 29
Koeppen, Wladimir, 28, 29

L

Lag of temperature, 100
Law latitude or tropical zone, 76
Locational setting, 1-25
    India and the oriental world, 17-18
    – frontiers, 8
        land frontiers, 8-10
        water frontiers, 10
    introduction, 1
    land of diversities, 12-14
    – – potentialities, 15-17
    location and size, 1-4
        India and the world, 4-5
    neighbouring countries, 17
    political divisions, 20-24
    routes into India, 10-12
    strategic significance of India, 18-20
    trade and commerce, 5
    unity in diversity, 14-15

M

Mahabharata, 15
Maldive, 17
Manipur, 21
McMohan, Henry. 9
Mean daily temperature, 100
Meridional heat transport, 85
Meridional transport, 87
Middle latitude zone, 76
Middle layer, 43

Mistress of the Eastern Seas, 18

N

Natural vegetation and forest resources, 243-281
  Alpine forests, 253-254
  animal products, 267
  classification according to composition, 255
  – – – exploitability, 255-256
  – based on ownership, 254-255
  – of natural vegetation, 244-245
    moist tropical forests, 145
  drugs, spices and poisons, 266
  dry tropical forests, 248
    tropical dry evergreen forests, 248
    – – deciduous forests, 248-250
    – thorn forests, 250
  edible products, 266-267
  factors affecting vegetation, 243-244
  fibres and flosses, 265-266
  forest conservation, 273-276
  – policy and law, 270-272
  – problems, 269-270
  forests products, 261
    major, 261-263
    minor, 263
  geographical distribution of forest area, 256-260
  grass lands, 260
    low land, 261
    riverain, 261
    upland, 260-261
  grasses, bamboos and canes, 263-264
  gums and resins, 265
  indirect uses of forests, 268-269
  introduction, 243
  leaves, 266
  legal or administrative classification, 254
  moist alpine scrub, 254
    tropical wet evergreen forests, 245-246
    – semi-evergreen forests, 246
    – moist deciduous forests, 246-247
    littoral and swamp forests, 247-248
  montane sub-tropical forests, 250
    sub-tropical broad-leaved hill forests, 250-251
    – – moist pine forests, 251
    – – dry evergreen forests, 251
  montane temperate forests, 251
    Montane wet temperate forests, 251-252
    Himalayan moist temperate forests, 252
    – dry temperate forests, 252
  oils, 265
  reservation of wildlife, 276-278
  social forestry, 272-273
  tans and dyes, 264-265
  wildlife, 278-280
Neighbours, 3
Net radiation and latitudinal heat balance, 85-87
No-man land of mountains, 10
North American Prairie, 58
North-East Frontier Agency (N.E.F.A.), 21

O

Ozone, 82, 91

P

Partition of the country, 8
Peninsular plateau, 200
Perihelion, 126
Photosphere, 74, 84
Polar zone, 77

R

Radiosondes, 68
Ramayana, 15
Relief and geology, 157-242
  agriculture, 188
  Archaean rock system, 219
    Dharwar system, 220-221
    genesis and schists, 219-220
  Aryan rock system, 225-227
  Brahmaputra plain, 199-200
  central highlands, 166-167
  climatic influence, 187
  coastal plains, 167-169, 213
  coastline of India, 233-235
  Daccan plateau, 167
  – trap, 227-228
  Degana, 194
  division of the Himalayas, 173
    great Himalayas, 177-178
    Himalayan ranges, 173-174
    middle or the lesser himalaya, 175-176
    Shiwalik range, 174-175
    trans Himalayas, 178-179
  Dravidian rock system, 223-225
  Drian, 193
  earthquakes, 235-239
    Himalayan zone, 239-240
    Indo-Gangetic zone, 240
    peninsular zone, 240-241
  east coastal plains, 216-218
  eastern hills, 179-180
  fertile soil, 186
  forest wealth, 188
  geomorphology of the plain, 191
    bhabar, 191
    bhangar, 192
    bhur, 192
    khadar, 192
    reh, 192
    tarai, 191-192
  glaciers of the Himalayas, 183-185
  great mountains of the north, 160-163
  – plain of north India, 188-189
  hill ranges of the peninsula, 207-208
    Aravali range, 208-209
    Eastern Ghats, 211-213
    Satpura range, 209-210
    Vindhya range, 209
    Western Ghats, 210-211
  Himalayan mountains, 169-170
  hydroelectricity, 186
  Indian islands, 201-202
  introduction, 157-160
  – to geology, 218-219
  islands, 169
  major physiographic divisions, 160
  Marusthali, 193
  Marwar plain, 193
  middle Ganga plain, 197-198
  minerals, 188
  Northern plains, 163-166
  origin of the Himalayas, 170-173
  – – the plain, 190-191
  peninsular plateau, 166, 200-201
  pilgrimage, 187-188
  plateaus of the peninsula India, 203

    Baghelkhand, 204
    Bundelkhand, 203-204
    Central highland, 203
    Chhattisgarh plain, 207
    Chota Nagpur plateau, 204-205
    Deccan plateau, 206-207
    Malwa plateau, 204
    Marwar upland, 203
    Meghalaya plateau, 205-206
  Purana rock system, 221
    Cuddapah, 221-222
    Vindhyan, 222-223
  Rajasthan Bagar, 193
  regional division of the Himalayas, 180
    Assam, 182
    Kumaon, 181
    Nepal, 182
    Punjab, 181
  regional divisions of the great plain of India, 192
  rohi, 193
  sambhar, 194
  sargol, 194
  significance of the coastal plains, 218
  – – – Himalayas, 186
  – – – peninsular plateau, 213
  – – – plains, 202-203
  sources of rivers, 186
  syntaxial bends of the Himalayas, 182-183
  tertiary system, 228-232
  tourism, 186-187
  Vulcan city in India, 241-242
  west coastal plains, 213-216
Rivers
  Beas, 304
  Brahmaputra, 312-314
  Chambal, 308
  Chenab, 303, 305
  Damodar, 309
  Gandak, 310
  Ganga, 306-311
  Ghaghra, 309
  Godavari, 315
  Indus, 302-306
  Jhelum, 303, 305
  Kali, 310
  Kosi, 310
  Krishna, 316
  Mahanadi, 314
  Mahi, 322
  Narmada, 318, 319
  of the Himalayan, 13
  – – peninsular India, 322
  Ramganga, 309
  Ravi, 304-305
  Sabarmati, 321
  Son, 308
  Tapi, 321
  Yamuna, 307

S

Shrub savanna, 44
Snowfield, 129
Soil conservation
  afforestation, 153
  changing agricultural practices, 153-155
  checking overgrazing, 153
  constructing dams, 153
Soil, 133-156
  alluvial soils, 136-137
  arid and desert soils, 143-144
  black soils, 137-140
  forest and mountain soils, 142-143

  introduction, 132
  laterite and lateritic soils, 141-142
  major soil groups of India, 135-136
  natural vegetation, 134
  parent material, 134-135
  peaty and marshy soils, 144
  red soils, 140-141
  saline and alkaline soils, 144
  soil formation in Indian conditions, 133
    climate, 133-134
Soil erosion, 145-153
  achievements in soil conservation, 149-151
  extent of soil erosion, 148-149
  human factors of soil erosion, 147
  – – – deforestation, 147
  – – – faulty methods of agriculture, 148
  – – – overgrazing, 147-148
  soil conservation, 151-153
  types of soil erosion, 145
  – – water erosion, 145-146
  – – wind erosion, 146-147
South American Pampas, 58
Specific heat, 104
States Reorganisation Act 1956, 21
Stratopause, 90
Stratosphere, 89
Subtropical Humid Climate, 50

T

Taylor, G.F., 95
Temperature, 124
Temperature gradient, 116
Thermometers, 124
Thornthwaite scheme, 29
Thornthwaite, C.W., 28, 29
Tibetan river, 300
Tree Savanna, 4
Trewartha, G.T., 28, 29-34, 73, 84
Tropic of Cancer, 4, 6, 7
Tropopause, 89, 107
Tundra climate, 72
Twilight, 127
Types of temperature inversion, 109
  advectional inversion, 109
  frontal or cyclonic inversion, 113
  mechanical inversion, 109
  non-advectional inversion, 109
  surface inversion, 113
  upper air inversion, 111
  valley inversion, 113

W

Wave frequency, 75
West flowing rivers of the peninsula, 318-323
  Mahi, 322
  Narmada, 318, 319
  Sabarmati, 321
  Tapi, 321
  west flowing rivers of the Sahyadris, 323
World climates, 27

Y

Yamuna, 307

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